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PROJECTION-TELEVISION RECEIVER

II. THE CATHODE-RAY TUBE

by J. de GIER.

621.397.62:621.385.832

A description is given of cathode-ray tube type MW 6-2. This tube produces a television picture of about 3.6 cm × 4.6 cm which, by means of a suitable optical system, is enlarged and projected on a screen (32 cm × 40 cm). The electron beam is focused and deflected by means of magnetic fields. The tube is designed to operate with an anode voltage of 25 kV. The "gun" is a triode system with a spark-trap. In order to produce a white picture, a mixture of two luminescent substances is used, one of which gives a yellow light and the other a blue light. An important element in the construction is the reflector, consisting of a thin layer of aluminium applied on the inside of the luminescent screen. By means of this reflector the luminescent light radiated to the rear is thrown forward, so that little is lost. Other advantages obtained with this reflector include improved contrast between the light and dark parts of the picture and the avoidance of an ion spot. Discoloration of the glass, a phenomenon that has been found to be due both to X-rays and to electrons penetrating the glass, is also discussed; a glass has been developed which shows no discoloration.

In the previous paper [1]) of this series on television reception — which paper we shall refer to here as article I — a summary was given of a number of drawbacks of the so-called "direct viewing" method when a fair-sized picture is required. Briefly, the objections were as follows: when a large cathode-ray tube capable of withstanding atmospheric pressure is used, either the tube face (the carrier of the luminescent screen) has to be given a strong curvature or the glass has to be made very thick. The former causes the picture to be distorted whilst the latter involves considerable thickness (one centimeter or more for the largest tubes having a diameter of about 50 cm) of the glass through which the picture has to be observed; moreover, such a bulb is most awkward to handle. In either case the risk of implosion has to be considered, and precautions have to be taken against this danger. Obviously such a tube is expensive and the cabinet in which it is mounted has to be of comparatively large size.

From the point of view of the tube manufacturer there are still other objections to be raised: large machines are required for the sealing, pumping and other processes, a great deal of space is required in which to store the bulbs and the completed tubes, and the cost of packing and transport is considerable.

All these objections disappear when a **small** cathode-ray tube is used and the picture is enlarged by means of projection. In article I a description was given of the modified **Schmidt** optical system that has been designed in the Philips laboratory for this purpose. It has been calculated that the cathode-ray tube requires a power of 2.5 W to give the projected picture of 32 cm × 40 cm the brightness of a good cinema picture, which is about 32 candles per sq. metre. Although the tube is capable of producing a much higher degree of brightness, the calculations which are to follow will be based on these figures.

In article I the choice of the tube voltage and tube current, the product of which yields this power, was left open. Since this is a matter closely related to our aim of minimizing the size of the light spot describing the picture as it passes to and fro across the window, this is the appropriate place to consider the choice of tube voltage and current, for the diameter of the light spot is directly related to several main dimensions of the cathode-ray tube and of the optical system, as will be evident from the following. In the ideal case the light spot is sharply defined and so small that the lines of the television picture just become contiguous. The height of the picture on the tube window therefore equals approximately the number of lines [2]) multiplied by the diameter of the spot. From this picture height there follows the picture width — which bears a certain proportion to the height — and thus also the diagonal determining the diameter of the window (with the British television system for instance the width is 5/4 × the height and the diagonal 6.4/4 × the height; with the American system these ratios are 4/3 and 5/3 respectively). Consequently, the more the spot can be reduced in size, the smaller the cathode-ray tube and the optical system can be made.

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[1]) P. M. **van Alphen** and H. **Rinia**, Projection-television receiver, I. The optical system, Philips Techn. Rev. 10, 69-78, 1948 (No. 3).

Choice of current and voltage

In point of fact the light spot is not sharply defined, its brightness being maximum in the middle and decreasing towards the edge. Defining the spot diameter d as being the diameter of the circle where the brightness is half of that in the centre, we can write the formula for d [3]) as:

$$d = C\left(\frac{I_a}{V_a \cdot j_k}\right)^{\frac{1}{2}},$$

where I_a represents the current flowing through the tube, V_a the voltage across the tube and j_k the current density at the cathode, whilst C is a factor that can be disregarded in the present case. From this formula it follows that in order to obtain the smallest possible spot one must choose a low current, but on the other hand the highest possible voltage across the tube and current density at the cathode. By increasing the current density, however, there is a danger of shortening the lifetime of the tube, whilst increasing the voltage likewise leads to a limit above which the difficulties are disproportionately increased. It was found that with a voltage of 25 kV these difficulties can quite well be overcome and this voltage has therefore been chosen for the tube to be presently described [4]). Naturally, steps have been taken to make it impossible for anyone to touch live parts. From the power of 2.5 W required for a satisfactory brightness of the picture on the projection screen it follows that a current of 0.1 mA is needed. With this current and a picture height of 3.6 cm good line definition is indeed obtained, even with the large number of lines (567) on which the experimental transmitter at Eindhoven is working, This gives a spot diameter of about 70 μ [5]). The cathode-ray tube, however, has so much reserve as to allow of higher current peaks (up to 0.5 mA), so that if it is desired the brightness can be appreciably increased (to about 120 candles/m², i.e. about 35 foot-lambert on the viewing screen, corresponding to a tube face brightness in the order of 10 000 c/m², or 3000 foot-lambert). The spot diameter is then increased, it is true, and the picture is thus less sharply defined, but as long as the lack of sharpness is confined to a few "high lights" this need not be troublesome.

The fact that the spot becomes larger when the current is increased can be seen from the formula given for d when it is borne in mind that then a larger surface of the cathode takes part in the emission, so that j_k does not increase so quickly as I_a. Moreover, when a high current is used account has to be taken of an effect which has been ignored in the deduction of the formula, namely the mutual repulsion of the electrons in the beam. This also means that the spot has a tendency to become larger.

The picture height of 36 mm leads to a diagonal of about 60 mm. The outer diameter of the tube face is about 65 mm.

Magnetic versus electric focusing and deflection

For the focusing as well as for the deflection of the electron beam either an electric field or a magnetic field can be used. In the case of a cathode-ray tube for a projection television receiver a magnetic field is to be preferred for both purposes, contrary to the case of a normal oscillograph tube for instance. This preference is due partly to the high voltage required for television tubes.

Let us first consider the deflection. If this were to be done electrostatically, a saw-tooth voltage of very large amplitude (of the order of 1000 V) would be required between the deflecting plates, owing to the high speed of the electrons. The generating of such a high saw-tooth voltage, which must satisfy stringent requirements of linearity, is no easy matter. Furthermore, the high D.C. voltage across the tube would involve the following difficulty. If the anode were to be earthed (as is usual with an oscillograph tube) the receiver supplying the video signal to the cathode and control grid of the cathode-ray tube would have to have a high (negative) voltage with respect to earth. If, on the other hand, the cathode were earthed then the generators of the saw-tooth voltages would come under a high (positive) voltage with respect to earth. Either case leads to unpleasant complications. With magnetic deflection these difficulties do not arise. Electrically the coils exciting the magnetic deflection fields [6]) are separated from the tube and can therefore be kept at earth potential. Then the cathode can be earthed, so that the problem of insulation does not arise in the receiving set either.

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[2]) The numbers of lines at present employed are: 405 in the British, 455 in the French and 525 in the American television system.

[3]) See for instance G. A. Morton, Electron guns for television application, Rev. Mod. Phys. 18, 362-378, 1946.

[4]) A specially suitable apparatus for this high D.C. voltage will form the subject of another article in this series.

[5]) During the flyback of the light spot from the bottom to the top about 10% of the number of lines is lost.

A third argument in favour of magnetic deflection lies in the fact that a certain error occurs to a much less extent than it does in the case of electrostatic deflection[7]). The fact is that with electrostatic deflection the voltage between the deflecting plates causes the electrons to be accelerated on the side of the positive plate and retarded on the side of the negative plate. The accelerated electrons are deflected over a smaller angle than the retarded ones, so that the light spot, which is circular so long as it is in the middle of the tube face, when deflected is drawn out to a small line. In the case of magnetic deflection in principle such a deformation likewise occurs, though from a different cause: the deflecting magnetic field has not precisely the same strength at all points of the diameter of the electron beam, so that the electrons are not all deflected to the same extent. The diameter of the beam can be kept so small, however, that the inhomogeneity of the field within that diameter can be ignored in this case.

Now as regards the focusing a factor in favour of the magnetic method is the extreme simplicity that can then be given to the electrode system (the "gun"), for this system, to which we shall refer presently, then need only consist of a cathode, a grid and an anode, as diagrammatically represented in *fig. 1.* The focusing coil around the neck of the tube is then at earth potential, as are also the deflecting coils.

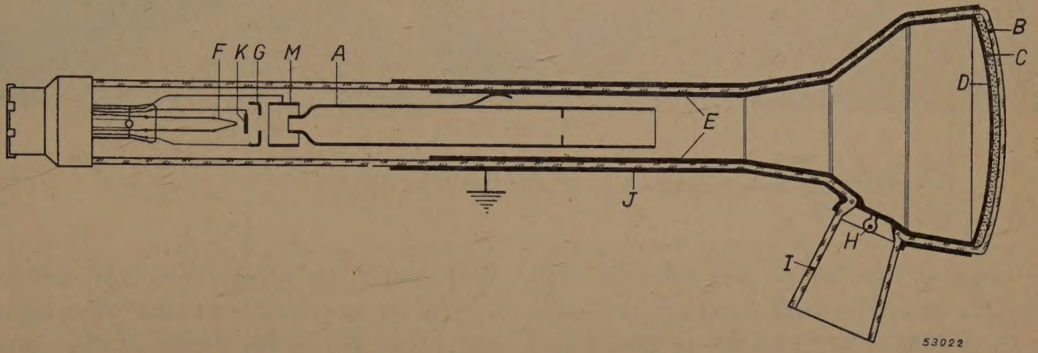

Fig. 1. Cross-section of the cathode-ray tube type MW 6-2 for projection television reception. F = filament, K = indirectly heated oxide cathode, G = grid, A = anode (the shape of these electrodes is only diagrammatically represented), B = spherically curved tube face, C = luminescent screen, D = reflector, E = conducting layer (continuation of D and at the same time forming connection to A), H = anode connecting lug, I = insulator for extending the leak path between the anode connection and the earthed conducting outer coating (J), M = spark-trap (referred to later).

Constructional features of the new cathode-ray tube

In article I it was recalled that Philips brought onto the market a cathode-ray tube for television projection as far back as 1937 [8]). Since that time considerable improvements have been made in the construction, some of which will be discussed here. The appearance of the new tube (type MW 6-2) may be seen from the specimen *3* shown in *fig. 2*, the I_a characteristic of which is given in *fig. 3* as a function of the grid voltage V_g.

The electrode system

One demand that has to be met by an electrode system for a cathode-ray tube is that it must produce a sufficiently narrow electron beam. This is above all necessary to minimize the aforementioned aberration that occurs through deflection. Moreover, the largest diameter of the beam must still be small enough to ensure also that the maximum deflected electrons are kept a certain distance away

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[6]) The apparatus supplying the saw-tooth currents for these coils will be described in a further article.

[7]) See for instance fig. 5 and the relative text of the article by J. de Gier and A. P. van Rooy, Improvements in the construction of cathode-ray tubes, Philips Techn. Rev. **9**, 180-194, 1947 (No. 6).

[8]) M. Wolf, The enlarged projection of television pictures, Philips Techn. Rev. **2**, 249-253, 1937.

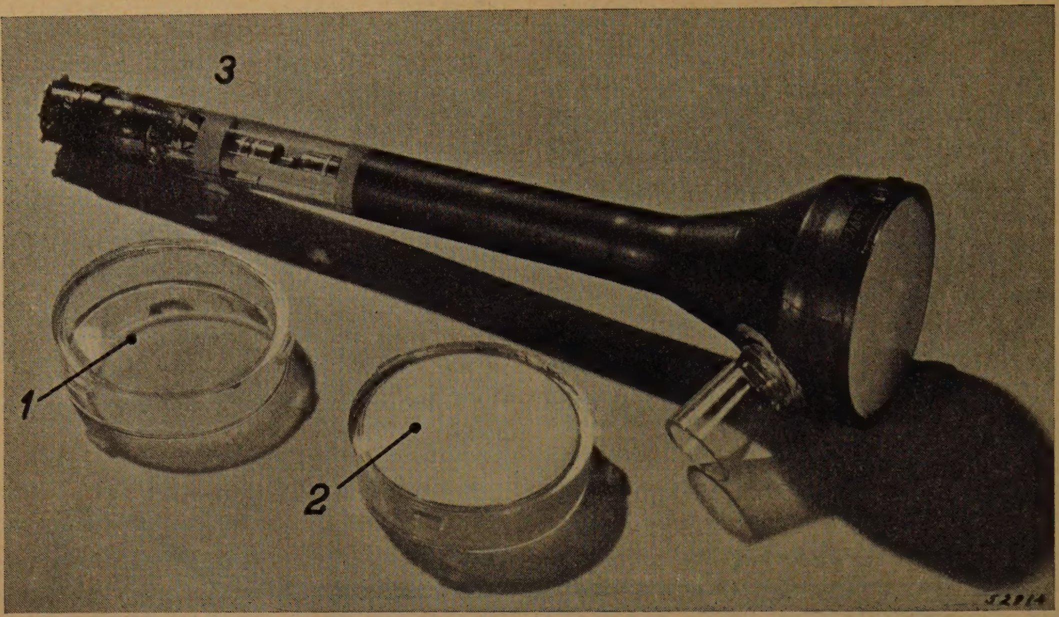

Fig. 2. *1* = tube face before the luminescent screen has been applied, *2* = tube face with luminescent screen, *3* = the complete tube MW 6-2.

from the edge of the anode and from the wall of the tube. On the other hand, however, the beam must not be so thin as to cause the mutual repulsion of the electrons to contribute perceptibly towards blurring of the light spot.

Further, the gun must be so arranged as to give a sufficiently steep $I_a = f(V_g)$ characteristic.

In the past it was thought that these demands could only be met by means of rather complicated constructions, for instance with a tetrode system comprising a "suction anode". It has been found, however, that also a triode system can produce field conditions which meet the requirements, if special attention is given to the following: shaping of the anode and of the profile of the opening in the grid, distance between anode and grid, and insertion between anode and grid of a ring connected to earth (which ring, as will be seen later, has also another function).

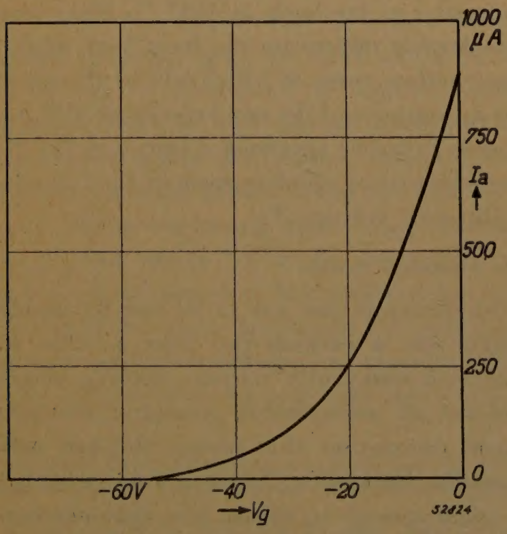

Fig. 3. Characteristic (anode current I_a as function of the grid voltage V_g) of the cathode-ray tube MW 6-2 for the normal values of the filament voltage and anode voltage (respectively 6.3 V and 25 000 V).

A triode system such as represented in *fig. 4* is, for various reasons, by far preferable to the older and more complicated constructions. With those older constructions it was not easy to centre the narrow aperture in the grid and in the suction anode with the necessary precision and to keep it centered. With the triode system, on the other hand, the centering of the grid with respect to the anode, which has a large aperture, does not present any particular difficulties. Especially satisfactory in this respect is a system already described in this journal [9]) where the electrodes are supported by ceramic insulators in the form of a small rod having a groove filled with sintered glass in which the electrode supports are fused.

A particular feature of the triode system applied in the MW 6-2 tube is the so-called spark-trap. This is the ring-shaped electrode already mentioned (*M* in fig. 4) which is placed between the grid and the anode and connected to earth. The purpose of this spark-trap will be seen from the following. If some gas should be released in the tube, for instance owing to overloading, then with the high anode voltage applied this might well give rise to a discharge between anode and cathode. This discharge might lead to a discharge between anode and cathode. The latter discharge might strike the grid and temporarily cause the grid voltage to be so highly positive as to damage the cathode ¹⁰). The spark-trap is placed in such a position that any discharge can take place only between this trap and the anode and in such a way as not to strike the grid. Thus, in the event of a flashover, the spark-trap avoids damage to the tube.

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[9]) See fig. 4 of the article quoted in footnote [7]).

troublesome blurs following rapidly moving objects in the television picture. In the article referred to in footnote ¹²) a number of silicates and sulphides are mentioned which give good results.

Reflector behind the luminescent screen

An important improvement is the reflecting layer of metal applied to the back of the luminescent screen, so that the light irradiated to the rear is reflected back again and thus contributes towards a greater brightness of the picture. Of course this layer must not obstruct the electrons in the beam, which have to penetrate through it, so that it must be extremely thin. Although the idea of such a reflector is nothing new, until 1940 it had not been applied to any extent worth mentioning, because no satisfactory method had as yet been found. The fact is that if the obvious method is employed — evaporating a suitable metal directly onto the luminescent screen — the result is usually just the opposite of what is required, the light yield being less than it would be without the metallic layer, instead of almost twice as great, as is to be expected theoretically. This adverse result is due mainly to the granular structure of the luminophores, the surface of which is like a mountain landscape, with the evapored metal precipitating for the most part on the peaks and in the valleys, and only little on the slopes; the layer on the slopes is thus more or less translucent and does not reflect so much light. Still more harmful is the effect of the metal precipitated in valleys which may be so deep as to reach down to the glass, for there a layer is formed which partly absorbs or reflects back the light emitted forwards.

During the war research was carried out in various countries in order to arrive at a process which

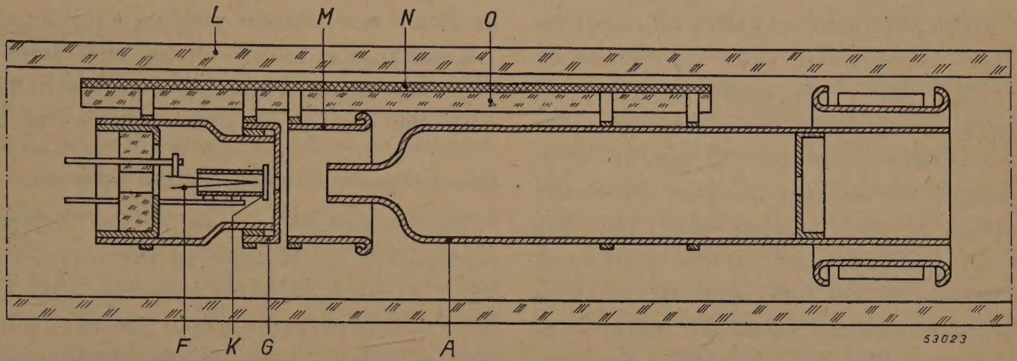

Fig. 4. Cross-section of the "gun" of the cathode-ray tube MW 6-2 enlarged about 2 ×. F = filament, K = cathode, G = grid, A = anode, L = tube wall, M = spark-trap, N = ceramic supporting insulator with glass filling G.

The tube face and luminophores

As already mentioned in article I, when a Schmidt optical system is used for the projection, the face of the cathode-ray tube has to be spherically curved in order to get a sharp projection on a flat screen ¹¹). The radius of curvature has to be about half that of the concave mirror. The tube face consists of a separately prepared piece of pressed glass (*1* in fig. 2). After the luminescent screen has been applied on the inside (*2* in fig. 2) the window is fused onto the conical part of the bulb.

In order to obtain the bluish-white tint that has been found best for black-and-white television pictures, a mixture of a yellow and a blue luminescent substance ¹²) is used, in such proportions that the colour temperature amounts to about 6500 °K. Luminophores should be chosen which have only a short persistence, because otherwise there would be

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¹⁰) Cf. H. C. Hamaker, H. Bruining and A. H. W. Aten Jr. On the activation of oxide-coated cathodes, Philips Res. Rep. 2, 171-176, 1947 (No. 3).

¹¹) Looked at from the outside, the tube face must appear convex, in contrast to the tube of 1937 (see footnote ⁸)) which was used in combination with a lens and had a concave window.

¹²) F. A. Kröger, Applications of luminescent substances, Philips Techn. Rev. 9, 215-221, 1947 (No. 7).

would give a good reflecting layer[13]). The solutions found are based on one of the two following principles: 1) first a filler is applied to the luminescent layer to fill up the valleys, the metal then being evaporated onto the plateau thus formed; 2) a film is stretched over the peaks so as to act as sub-layer for the metal. It is this latter principle that is applied in the Philips projection tube. With the process worked out at Eindhoven the film consists of an organic substance which, after the metallic layer has been applied, can be removed by burning or evaporation.

The metal commonly used for the reflector is aluminium, which combines a number of properties favourable for the object in view. Its reflectivity for light is high (85% can easily be reached), whilst owing to its fairly low atomic weight (27) electrons can readily penetrate through it. It is easily evaporated, for instance from an electrically heated tungsten or molybdenum wire. The thin layer of oxide, Al_2O_3, formed on the aluminium during the heating of the bulb and the pumping is transparent and does not affect the reflectivity; it has even a favourable effect, in that it protects the underlying aluminium layer against chemical attack in the manufacturing process and against atomisation by the impinging electrons.

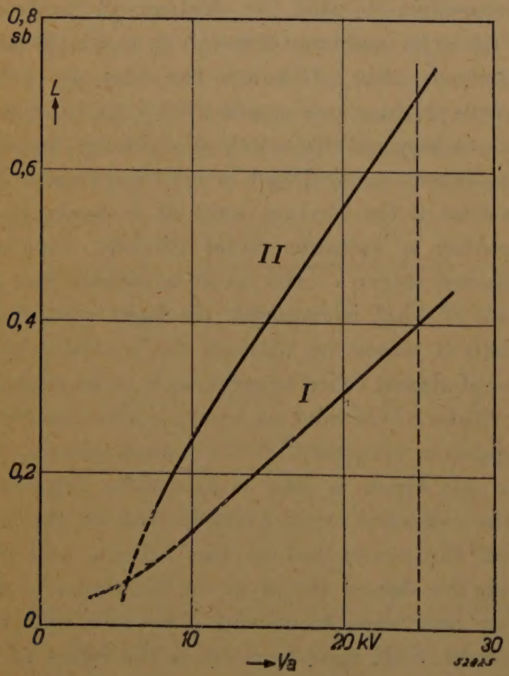

Fig. 5. Brightness L (in stilb = candle/m^2) of a cathode-ray tube in the forward direction as function of the anode voltage V_a; I) without, II) with reflector behind the luminescent screen. In both cases the anode current was 200 μA.

The layer of aluminium has to be of such a thickness as to be opaque but at the same time thin enough as to absorb only very little energy from the electrons. The first requirement is already met at a thickness of 0.5 μ, and since the penetration depth of electrons with a velocity of 25 kV is from 5 to 10 μ [14]) (according to the definition given to penetration depth) it is obvious that in such a thin layer rapid electrons will lose but little energy.

In *fig. 5* we have plotted as a function of the voltage the brightness of the tube face in the forward direction at a given intensity of current: *I*) without reflector and *II*) with reflector. It will be seen that at 25 kV the reflector yields a gain factor of about 1.8, and that at lower voltages this factor decreases. (This constitutes yet another argument for working with the highest possible voltage on the tube).

Other favourable effects of the reflector

The favourable action of the reflector is not confined to an increase in the useful quantity of light. Another desirable property is its high electric conductivity, which prevents potential differences arising between the anode and the luminescent screen and between different parts of the latter. As a consequence there is more freedom in the choice of the luminophores, since substances can be used which could not previously be considered on account of their weak secondary emission; in the absence of a metallic layer the use of substances deficient in secondary emission would lead to local negative charges on the screen which would repel the electron beam (until the charges have sufficiently disappeared) and thus cause irregularly flickering spots in the picture.

Further, the aluminium layer enhances the contrast between the light and dark parts of the picture. Without this layer a bright part on the luminescent screen might radiate light to a dark part (both directly along a chord of the curved tube face and *via* reflection on the inner wall of the bulb cone); due to scattering, this light would also partly radiate towards the observer and thus reduce the original contrast.

Finally, the aluminium layer, provided its thickness has been properly chosen, is an effective remedy against the phenomenon called the ion spot. While the tube is working, negative ions are formed (negatively charged O-atoms, O_2-molecules,

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[13]) See e.g.: D. W. Epstein and L. Pensak, Improved cathode-ray tubes with metal backed luminescent screens, R.C.A. Rev. 7, 5-10, 1946.

[14]) See for instance P. Lenard, Quantitatives über Kathodenstrahlen, aller Geschwindigkeiten, Heidelberg 1925; E. Rutherford, J. Chadwick and C. D. Ellis, Radiations from radioactive substances, Cambridge 1930, chapter XIV; F. Rasetti, Elements of nuclear physics, London and Glasgow 1937, page 68.

OH-groups, etc.) which arise from gas residues or are released from the cathode. The mass of these ions being much greater than that of the electrons, they are not appreciably deflected in the magnetic field and thus tend to concentrate continuously on the middle of the screen. This concentration would result in a gradual decrease in the luminescence at that spot if there were no protective layer of metal. In course of time the picture would show a dark spot in the middle, the ion spot. The aluminium being a perfect safeguard against the ion bombardment, no trouble is experienced from this phenomenon.

Discoloration of the glass

In cathode-ray tubes at high anode voltages from about 15 kV upwards a phenomenon occurs which is not evident when lower anode voltages are used. This phenomenon is the discoloration of the glass of the tube face. After the tube has been used for some length of time, the rectangle of the television picture can be seen marked on the tube face in a certain colour (purple, brown or black according to the composition of the glass), when the tube is switched off. This may lead to as much as 20% absorption of light, but still more serious is the unpleasant tint given to the picture.

This phenomenon has been thoroughly investigated and it has been found that there are two causes for the discoloration: the soft X-rays arising from the electron bombardment on the luminescent grains, and the rapid electrons impinging directly upon the glass.

As already known from literature on the subject, the discoloration due to X-rays can be removed by heating the glass to 200-400 °C or exposing it for a long time to daylight.

The discoloration found in many kinds of glass as a result of the action of rapid electrons is of an entirely different type. In a cathode-ray tube this may occur when the luminescent layer is not of such a uniform thickness as to absorb all the electrons. For an optimum luminosity of the layer its average thickness must lie between narrow limits. It appears that with this average thickness it is possible for the electrons to pass through the layer, at least at the thinner parts, and still retain enough energy to penetrate into the glass. The discoloration due to this penetration of electrons cannot be so easily removed as that caused by X-rays. It is limited to a very thin layer only a few microns thick, whereas the discoloration due to X-rays may extend to a depth of a millimeter in the glass.

The extent to which these two effects occur in different kinds of glass varies considerably. Research undertaken by Philips has led to the composition of a special glass that shows neither of these two discolorations. A limiting factor in this research was the requirement that the new glass must be capable of being fused onto the glass of the other part of the bulb.

Conducting layers on the bulb

As in the case of all cathode-ray tubes, the inside of the bulb has to be covered with a conducting layer connected to the anode so as to prevent charging of the glass. Before the reflector described above was introduced reflection from the wall of the bulb had to be avoided, as otherwise there would be troublesome reflections of the picture. Consequently a dull black substance had to be used for the conducting layer, for instance graphite. This substance is often applied in the form of Aquadag, i.e. colloidal graphite suspended in a solution of organic components in water, the water being subsequently evaporated. From the tube manufacturer's point of view Aquadag has two drawbacks: 1) particles of graphite settling on the cathode greatly reduce the emission; 2) the organic components give off gases which can only be removed by very careful evacuation.

By using the reflector, which prevents any radiation of light to the rear, there is no longer any fear of reflections on the wall of the bulb, so that now there is no objection to the conducting layer on the wall being reflective. Obviously there-

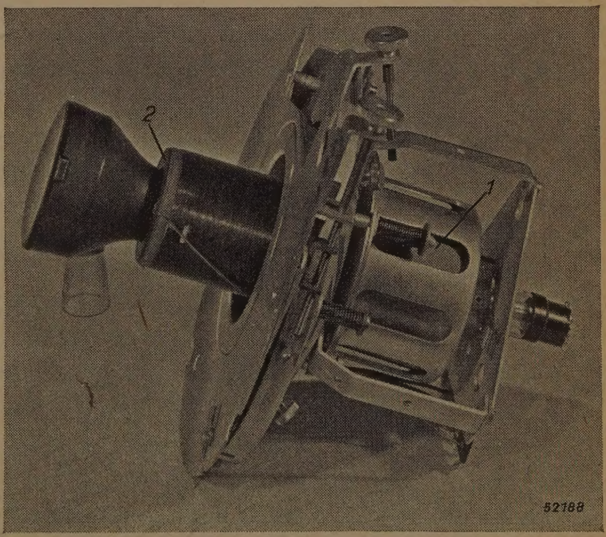

Fig. 6. The cathode-ray tube mounted in the holder for fixing it in position with respect to the projection optical system (cf. figs 6 and 7 of article I). *1* = focusing coil, *2* = cylinder containing the deflecting coils.

fore, instead of Aquadag, aluminium can now be used for the internal conducting layer, and this has in fact been applied in the MW 6-2 type of tube. This layer serves at the same time as a connection between the anode proper (*A*) and the anode connecting lug (*H* in fig. 1).

Aquadag is still used on the outside of the bulb to form a conducting layer connected to earth (*J* in fig. 1). Together with the layer of aluminium on the inside and the glass in between, this external layer forms a condenser helping to smooth the anode voltage. The capacitance is about 300 pF.

Data regarding focusing and deflection

Focusing of the electron beam is done by means of the coil *1* seen on the right in *fig. 6*, which has an iron magnetic circuit with an air gap of 1.2 cm. This circuit has about 800 ampere turns. The coil is fed from the high-tension supply unit of the receiver via a variable resistor with which the focusing can be adjusted.

The displacement x of the light spot on the screen of the tube MW 6-2, at 25 kV, is

$$x = 180\, lB,$$

in which l represents the axial lenght of the deflection coils (*2* in fig. 6) expressed in the same unit as x, and B the magnetic induction in the axis of the coils (in Wb/m^2). The induction required with a 5 cm coil to carry the light spot across to the edge of the 4.6 cm wide picture is thus $2.3/(180 \times 5) = 2.6 \times 10^{-3}$ Wb/m^2 (in e.m.u.: 26 gauss).

With an anode voltage of 25 kV and an anode current of 0.1 mA the brightness on the tube face is approximately 3600 candles/m^2. In article I it was roughly calculated that in order to give the picture on the frosted glass viewing screen a brightness of 32 c/m^2 the face of the tube has to yield a luminosity of 5 candles in the axial direction, corresponding to a brightness of about 3000 c/m^2. The tube MW 6-2 thus amply answers the requirement. Moreover, as already stated, current peaks up to 0.5 mA are permissible, so that locally a much greater picture brightness can be achieved.

A TRANSPORTABLE X-RAY APPARATUS FOR MASS CHEST SURVEY

by H. J. DI GIOVANNI *), W. KES *) and K. LOWITZSCH *).

621.386.14:616-073.75

The transportable apparatus developed by North American Philips Co., Inc., for mass chest survey by fluorograms of groups of industrial workers, schoolchildren and others, is described. The pictures are recorded on 70 mm-film by a Fairchild camera with automatic film strip advance after every exposure, allowing 375 pictures to be made in uninterrupted succession. Constant average density of all pictures is achieved by the application of the photoelectric Morgan-Hodges timer, which automatically terminates the exposure when the film has received enough light from the fluorescent screen. In addition to these elements, the apparatus contains a series of other error-precluding devices, such as an interlocking mechanism actuated by the examinee's identification card, that serves to avoid a possible mix-up of the fluorograms. The weight of the total installation, based on a maximum X-ray tube rating of 100 kV, 200 mA, is only 1212 lbs; this is achieved through the extensive use of magnesium alloy castings. The apparatus may be disassembled in 12 pieces, thus allowing very rapid mounting and dismantling at the site of the day's assignment. A number of further details of the equipment are described, e.g. the vertical adjustment of the X-ray tube and screen, the control panel, the photoelectric timer, etc.

The modern fight against tuberculosis has been aided during the past ten years by a new diagnostic tool: the fluorogram. This is an X-ray picture of the thorax on a reduced scale, obtained by photographing the X-ray shadow picture appearing on a fluorescent screen; cf. *fig. 1.* Small size pictures, e.g. on 35, 45 or 70 mm roll film, have proved capable of giving information as to whether a lesion in the lung tissues is present or not. Owing to the small film size, the series examination of large groups of an entire population is possible at relatively low cost and at a remarkably fast time rate. Thus, the method has proved extremely valuable for finding cases of pulmonary tuberculosis in the so-called symptomless stage (which offers best prospects for a successful treatment); more detailed diagnoses in the cases thus located can be obtained subsequently by the conventional full size radiographs.

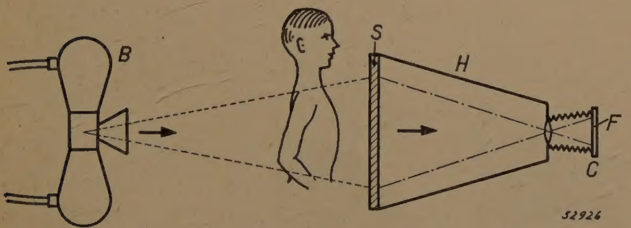

Fig. 1. General set-up for fluorography. The examinee is placed with his chest against a fluorescent screen *S* fixed to one end of a light-tight hood *H*. An X-ray tube *B* casts a shadow image of the chest on the screen. This image is photographed on a small size film *F* by means of a camera *C* fixed to the other end of the hood.

The principle of the method of fluorography, which was first put into a practical form by de Abreu [1]) in 1936, was discussed in this Review in an article in 1940, in which a series of experiments showing the usefulness of the method [2]) was also described. In order to give an idea of the large scale on which the method has been applied in the interim, it may be mentioned that during the years 1941-1944, 20 million fluorograms were taken in the U.S.A. alone [3]).

It is obvious that the problems of organization for smoothly handling such enormous numbers of examinees become pre-eminent. They can be solved only with the aid of a highly specialized equipment, and the solution will be different for different groups of the population. A successful mass survey is most readily conducted with (though not restricted to) coherent groups such as soldiers, industrial workers, school children and hospital admissions. A few words will be said about the last of these groups at the end of this paper; as to the other groups, there are two possibilities of organization, viz., bringing the equipment to the examinees, or the reverse. If the number of examinees in a specific locality warrants the application of the first procedure — and if the locality affords a suitable power line supply or if a suitable gasoline generator is available —, this procedure should be adopted. It offers the advantages of causing the examinees to lose a minimum amount of time and of preventing them, as far as possible, from missing the examination. Therefore, in developing a radiographic equipment suited for general mass chest survey purposes, an essential requirement — in addition to the desired high quality of the pictures — was portability, to be achieved through low weight, small volume, and easy mounting and dismantling. Other important requirements which were to be met in order to make a large scale application feasible were: complete reliability, simple and quick operation by relatively unskilled operators, and safeguards against all kinds of possible errors.

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*) North American Philips Company, Inc., New York, N.Y.

[1]) M. de Abreu, Z. Tuberkulose **80**, 70-91, 1938; M. de Abreu and A. de Paula, Roentgenfotografia, Livr. Ateneu Rio de Janeiro 1940. There were a number of precursors, i.a. Köhler and Biesalski (1909), Caldwell (1911), Gardner (1932), who saw the importance of the method, but had no adequate technical means for its successful realization.

[2]) A. Bouwers and G. C. E. Burger, X-Ray Photography with the Camera, Philips techn. Rev. **5**, 258-263, 1940 (No. 9).

[3]) Cf. H. E. Hilleboe and R. H. Morgan, Mass Radiography of the Chest, The Year Book Publishers, Chicago 1945.

Important contributions to the achievement of the latter aims were furnished by the development of automatic photographic cameras (Fairchild, Recordak), and of the automatic timing device of Morgan and Hodges[4]). Both devices, a few details of which will be discussed in the following pages, are incorporated in most of the commercially available types of apparatus which have been designed for mass chest survey purposes. They are included in the apparatus described in this paper,

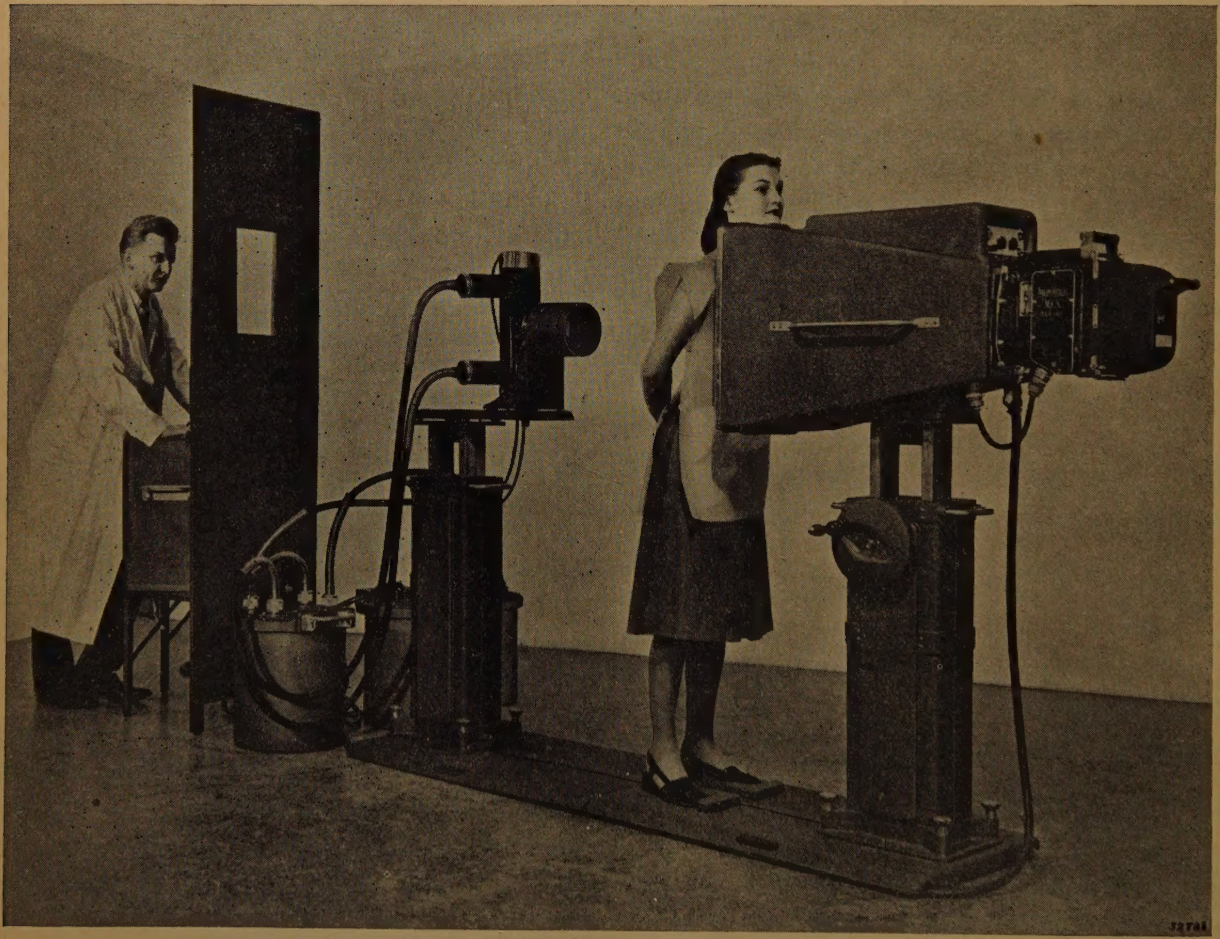

Fig. 2. Philips mass chest survey apparatus. X-ray tube and hood are mounted on two columns, clamped to a floor-plate. To the extreme right, the automatic Fairchild camera is fastened to the hood by two mounting hooks and two spring bands with a lock-type lever. The photoelectric timer is mounted in the top of the hood. The operator stands at the control panel behind a protective screen, where he can watch the examinee through a lead glass window. The three tank units located between the X-ray tube and the control panel, and linked to both of them by flexible cables, contain the two halves of the high tension transformer, each delivering up to 50 kV, and a bridge circuit with four high vacuum rectifying valves. In place of the two transformer units, which can supply 200 mA at 100 kV, a single unit can be optionally substituted delivering the total voltage of 100 kV with a maximum load of 100 mA. The leads connecting the camera and the photoelectric timer to the control panel are placed in a channel in the floor-plate.

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[4]) R. H. Morgan and P. C. Hodges, U.S. Patent 2 401 289. Cf. R. H. Morgan, Am. J. Röntg. 48, 220-228, 1942; Publ. Health Rep. 58, 1533, 1943.— Previous attempts to develop such a device were made by H. Franke: Fortschr. Röntg. 42 (Kongressheft), pag. 153-154, 1930.

along with a number of other features that warrant a more detailed description. This apparatus was developed by North American Philips Company, Inc., and has been in constant use at a number of Health Services throughout the U.S.A. and other countries during the past several years.

General description of the apparatus

A photograph of the complete equipment is reproduced in *fig. 2*. The X-ray tube and the hood with the camera, sketched in fig. 1, are mounted on two columns, whose relative position is fixed by a common floor-plate. The high tension generator consisting of three (or two) units, and a control stand for the operator are placed behind the X-ray tube. This arrangement requires a minimum of floor space and permits the working area around the unit to be kept free from obstructions such as cables, which is an important consideration when dealing with a more or less continuous stream of examinees.

The automatic Fairchild-camera, which is fastened to the small end of the hood, has been especially developed for miniature film radiography. It will accomodate a 100 foot strip of (unperforated) 70 mm roll film. After each exposure the film is transported automatically through one frame length by a small electric motor. Thus the task of the operator is facilitated and the risk of double exposures avoided. The picture size is 2.5″ × 3″, so that a 100 foot length of film permits 375 exposures to be taken without interruption for unloading and reloading the camera. Arguments concerning the most desirable picture size will not be appraised here. It may be stated, however, that — although smaller sizes are quite feasible and offer enhanced advantages of economy and easy handling — the 70 mm size has become rather popular because it permits the use of relatively coarse-grained and, therefore, very sensitive film material.

As a high speed optical system is of prime importance with fluorography, the Fairchild-camera contains a coated lens having an effective speed of $f:1.9$ (with a subject-to-lens distance of 78 cm), designed especially for this purpose. The reconciliation of the contradictory requirements of a large aperture and of extremely sharp images was considerably simplified by the fact that a single invariable subject-to-lens distance is required and that the problem of chromatic aberration was rendered less serious because the types of fluorescent screen used for fluorography emit light with a fairly distinct maximum in its spectral distribution, either in the blue or in the green region.

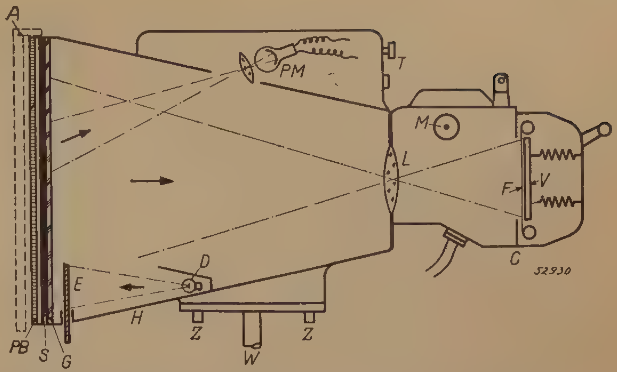

Fig. 3. Schematic cross section of the hood. In front of the screen *S*, which is backed by a clear glass plate *G*, a very fine meshed Potter-Bucky filter grid *PB* is placed, which reduces materially the scattered radiation and hence improves the contrast of the image. An adequately chosen rectangular portion of the chest image on the screen is projected by a lens onto the sensitive surface of the photo-multiplier tube *PM*, controlling the automatic timing of the exposure. The setting of the timer to the desired film density is done on the panel at *T*. Card *E* and lamp *D* are part of the identification and interlock system described in the following section. *W* and *Z* are pins for mounting the hood on its pedestal. *C* is the Fairchild "Fluoro-Record" camera, with lens *L* and motor *M* for automatic film transport. During the exposure the film *F* is pressed against the frame in the focal plane by a pressure-plate *V*; it is automatically released for transport after the exposure. X-rays transmitted by the fluorescent screen are almost completely absorbed by the camera lens and its steel fitting, so that no fogging of the film in the camera magazine will occur. If it is desired to make a full-size radiograph, an adaptor frame *A* for a cassette holder is hooked on the screen side of the hood.

The Morgan-Hodges-timer is placed in the top of the hood. This device controls the duration of the film exposure, de-energizing the X-ray tube automatically as soon as the given exposure that corresponds to the desired density of the fluorogram has been obtained. A cross-section of the hood showing the basic arrangement of the timer is given in *fig. 3*. An image of a portion of the fluorescent screen is focused by a lens on the light-sensitive cathode surface of a photo-multiplier tube. The electric current produced in the tube by the illumination charges a capacitor, and the voltage built up across it is applied to the grid of a relay-tube. When the voltage on the capacitor reaches a certain value, corresponding to a predetermined amount of light emitted by the fluorescent screen, the relay-tube is fired and interrupts the X-ray supply. A few more details of this mechanism will be described below.

The control-panel is shown in *fig. 4*. As it will be impracticable, in many cases, because of the limited time and supervisory personnel allotted, to determine and use the exact kilovoltage and current of the X-ray tube yielding best penetration and contrast with the specific chest dimensions of each individual examinee of a large group, medium values of e.g. 85 kV (peak) and 100 mA (mean value) are ordinarily adopted. Other values need be used only with persons of very unusual proportions. For this purpose, the kilovoltage may be adjusted to 75, 85 or 100 kV, while the current is adjustable to 50, 100 and 200 mA. The highest mA-value should be used only in places where the local power line has sufficiently small resistance not to produce too large a voltage drop with this heavy load.

The tube current is made independent of line voltage fluctuations by means of a filament voltage stabilizer, and the kilo-voltage is made independent of the tube current by a set of compensating resistors, utilizing a method recently described in this Review [5]). These precautions are taken in this apparatus only to obtain consistent contrast and sharpness of the radiographs; in contradistinction to normal diagnostic radiography they are not necessary for obtaining consistent film densities, this being insured by the automatic timer.

The exposure time necessary for an average chest size of 22.3 cm and with 100 kV and 100 mA is about 0.185 sec. For extreme chest sizes, exposure times under the same conditions may vary from about 0.1 to 0.6 seconds. Of course, with a given kilovoltage and tube current, the exposure time must not be so long as to cause an excessive heating of the anode of the X-ray tube. In order to insure that the time limit which corresponds to the permissible tube rating will never be exceeded, and also to protect the X-ray tube in case the photoelectric timer should entirely fail to function, a safety timer is provided which interrupts the X-ray tube supply (regardless of the action of the photoelectric timer) after a given time, set in accordance with the permissible tube rating to any one of seven values between 0.25 and 2.5 sec. Incidentally, the permissible exposure times with mass chest surveys are influenced by the great number of exposures which must be taken with only short intervals between them (on many assignments, 200 or 300 per hour).

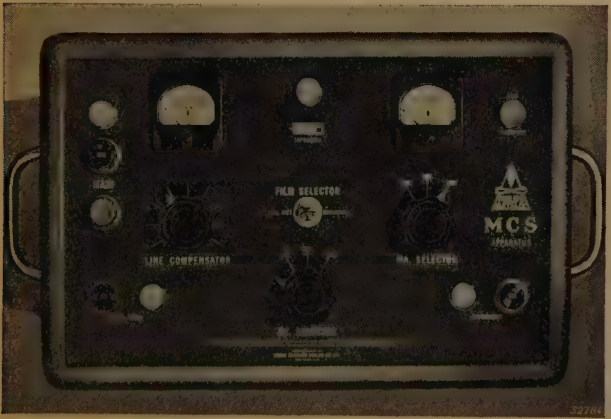

Fig. 4. View of the control panel of the apparatus. In the center is the switch for changing over from fluorography to full size radiography; below this switch is the control knob for kilovoltage selection, to the right, the mA-selector (with meter); to the left, the voltage adjusting knob (with meter) for compensating power line variations. Situated around these elements are pilot lights, the pushbutton for making the exposures and a register for counting the exposures. The circuits contained in the high tension generator, the photoelectric timer, the automatic camera and other devices are all connected to the control panel with plugs and jacks. All the plugs are coded and keyed in order to prevent the incorrect connection or accidental interchange of leads.

The height of the X-ray tube and the screen must be adapted to the height of the examinee. Therefore, a vertical adjustment of the hood by means of a crank-wheel is provided. The X-ray tube is linked to the hood by a chain running through a channel in the floor-plate, so that the tube follows the hood in its vertical movement. This mechanism is illustrated by *fig. 5*, in which a few more details of the design are also shown and explained. A foot form on the floor-plate and a chin-rest on the hood aid in rapid posturing of the examinee with respect to the screen.

The vertical adjustment may also be accomplished by means of a small motor provided with a special braking control developed for this specific purpose. The braking mechanism brings the fast running motor to a stop within two or three revolutions after the operating button has been released. This is very important when a quick adjustment is required, avoiding repeated overshooting.

Mechanical design of the equipment

As light weight is one of the most important requirements for transportable apparatus, magnesium was selected as the basic metal from which to fabricate the main assembly castings. Considerable experience has been gained before and during the last war by airplane manufacturers and aircraft parts foundries in handling this hitherto rather unfamiliar metal. For castings, the metal is generally used in the form of an alloy containing aluminum, small amounts of manganese, and sometimes zinc, e.g. 6% Al, 0.2% Mn, 3% Zn. The specific gravity of this alloy is about 1.8, i.e. it is about 1/4 that of iron and 2/3 that of aluminum, so that considerable saving in weight could be expected from the use of this material.

It is true that part of the gain achieved by the low specific weight is lost because of the less favorable mechanical properties of magnesium, viz., its low shock resistance and low elastic modulus, as compared with common aluminum alloys (the elastic modulus for the magnesium alloy mentioned above is 64 × 10^5 lb/in^2 (4.5 × 10^5 kg/cm^2), for aluminum alloys 100 × 10^5 lb/in^2). These properties require the adoption of thicker sections, added stiffening ribs, generous tapers from heavier to lighter sections and larger fillet radii (about twice those that would be used for iron castings). Nevertheless, the magnesium castings turn out to be lighter than if made of any other material. This is partly due to the fortunate fact that the provisions necessary for compensating for low elastic modulus and low shock resistance are similar.

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[5]) A. Nemet, W. A. Bayfield and M. Berindei, A diagnostic X-ray apparatus with exposure technique indication and overload protection, Philips Techn. Rev. 10, 37-45, 1948/49 (No. 2).

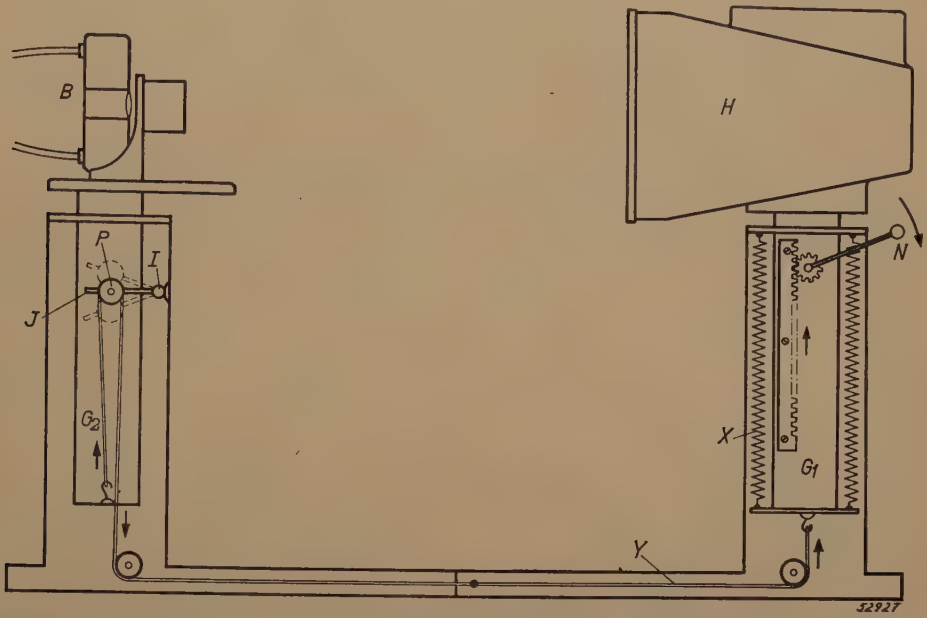

Fig. 5. The height of the hood *H* is adjusted by means of crank *N* and a rack and pinion drive. The X-ray tube *B* follows the hood in synchronous movement, due to the interconnection of the two supporting movable members G_1 and G_2 by chain *Y*. The total weight of hood and X-ray tube is, at a position of medium height, exactly counterbalanced by the tension of the springs *X*. Owing to the great length of these springs, their tension varies only slightly with the position of the hood; hence the counterbalanced condition is maintained to a good degree of approximation in all positions, and the adjustment of height requires negligible effort. (Counterbalancing by springs instead of by weight has the advantage of keeping the total weight of the apparatus and the inertia of the adjustable portions as low as possible.) The pulley *P* may be lowered or raised to two fixed positions other than the normal one by swinging the bearing arm *J* round its fulcrum *I* by means of a crank; in this way, stereoscopic pictures can be taken, as the X-ray source in one position of *P* is 5 cm below, and in the other one 5 cm above its normal height, thus producing two shadow images with the desired parallax. (In order to make separate sets of stereoscopic pictures, the roll film cassette of the camera can be substituted by a special adaptor for cut films; this is also most useful for making test fluorographs.)

In addition to their low density, magnesium alloys in general offer the advantage of very favorable machining characteristics, so that high tool speeds and deep cuts are possible. However, due to the unique mechanical properties, machining practice with respect to the cutter types and grinding and lubricating methods to be used is rather different from that in use for other metals. Ample data as to proper machining technique are available from the manufacturers of magnesium alloys 6).

Due to the extensive use of magnesium it was possible to reduce the total weight of the apparatus to 1212 lbs (with the 200 mA-generator; if the 100 mA-generator is used, the weight is only 1052 lbs).

Other important requirements for portable apparatus were mentioned above; small size, easy and quick mounting and dismantling. To reduce size, the largest component parts (operator screen and floor-plate) are made collapsible. On the other hand, the number of pieces into which the unit is disassembled is kept to a minimum, in order to reduce the time necessary for mounting and disassembling. There are only 12 major pieces, and the whole unit can be set up or dismantled in 15 to 20 minutes. The objective of reducing the number of pieces was not, of course, allowed to interfere with the requirement that each single piece must be easily handled. Accordingly the transformer of the 200 mA-generator is designed as two units to divide the weight (each of the two sections weighs 196 lbs).

The speed of setting up results partly from the simple way in which the columns with the hood and

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6) A curious detail of the machining of magnesium is the necessity of avoiding the hazard of fire: as is well-known, very fine magnesium chips are easily inflammable, as exemplified by the old-fashioned photographic flash powders. Therefore, special precautions are necessary in cutting and in disposing of the shavings.

the X-ray tube are assembled. The columns are fastened to the floor-plate by four integral clamping screws. The hood is simply placed on its pedestal inserting a mounting stud in the corresponding hole, two small auxiliary pins ensuring proper alignment. The X-ray tube and the tube support bracket are mounted in a similar way, suitable indexing arrangements being provided. The hood, bracket and tube are heavy enough to remain securely seated in their proper places without requiring any sort of clamping. The chain connecting the hood and the X-ray tube is composed of two parts, each part, upon disassembling the unit, being retractable into its respective column where it can be fastened in place. This automatically locks the sliding section of the tube column, so as not to risk damage during transport.

Error-precluding devices

The apparatus contains several devices to prevent operators from making errors which would cause damage to the equipment or impair the usefulness of the survey. The automatic motor-driven camera and the automatic timer, as error-precluding devices, were mentioned above. A few others are described here.

During the survey the possibility of mix-ups resulting from improperly identified photographs is completely eliminated by an identification system visible in the lower part of fig. 3. For every examinee, an identification card *E* containing name, serial number or other data must be properly inserted in a card holder in the hood. The proper insertion of the card operates a relay system, which is connected in the circuit in such a way that until it is operated the X-ray tube cannot be loaded. During the exposure the identification card is illuminated by a lamp *D* and photographed on the lower part of the fluorogram. After the exposure the apparatus is automatically interlocked, and only the extraction of the card from the holder and the proper insertion of a new one (or of the same card again, if a second exposure of the examinee is desired) will re-establish the conditions necessary for energizing the X-ray tube.

The actual exposure is effected by simply pressing a pushbutton on the control panel (cf. fig. 4) and holding it down. The relay system actuated by this button switches on the illumination for the identification card in the hood, boosts the filaments of the rectifying valves and energizes the stator of the X-ray tube, rapidly accelerating the anode to full speed (this, of course, applies only to the case of a rotating anode tube; tubes with stationary anode may also be used). Approximately one second after the button is pressed the X-rays come on, this condition being indicated by a red pilot light on the control panel. When the proper exposure time has elapsed, the X-ray tube is automatically de-energized by the photoelectric timer and the red pilot light is extinguished. Now the pushbutton can be released, whereupon the automatic advance of the film strip to the next frame takes place.

Releasing the pushbutton at an earlier moment will terminate the exposure and de-energize the apparatus at once. Thus, the operation remains continuously under control and may be interrupted without delay if this should be necessary.

In addition to the proper insertion of a new identification card, there are other conditions necessary to prepare the apparatus for the next exposure. If the end of the film strip has been reached, or if the camera magazine was accidentally left unloaded, no exposures can be made. A similar condition will exist when the safety timer has terminated an exposure before actuation of the photoelectric timer. This is indicated by a white pilot light on the timer panel. When this light is on, a reset button on the panel must be depressed in order to restore the normal conditions. This serves to direct the attention of the operator to the fact that the density of the preceding fluorogram will be low, as the full exposure time was not received. He can try, in that case, to repeat the exposure with a higher kilovoltage, yielding better penetration of the chest under examination.

In addition to the red and white pilot lights already mentioned, a blue light on the control panel is provided which blinks during the moving of the film, and a light marked "Ready" verifying that all conditions for making the next exposure are fulfilled.

As the remarkable simplicity of operation is largely due to the use of the photoelectric timer, a description of a few details of this device seems worth while. A simplified circuit diagram is shown in *fig. 6*. The timer can be preset to produce a fixed average density of the fluorograms by adjusting the amplification factor of the 9-stage photomultiplier tube. For this purpose the accelerating voltage between successive electrodes in this tube may be varied between 25 and 100 V, causing the amplification factor to vary between 100 and 10^6 and hence allowing variation by a factor of 10^4 in the exposure of the film before the X-ray tube is switched off. As for the reproducibility of the density (or the product of screen brightness and exposure time), it is clear from the above that the density obtained will be very sensitive to small voltage fluctuations on the phototube. Therefore, the voltage supply of the timer unit is stabilized. Another factor that had to be considered is the finite time required to open the contactor actuated by the ralay-tube of the timer. When no allowances for this are made, all exposure times t, "proposed" by the photo-multiplier tube, will be prolonged by this constant break-contact time T, which amounts to about 1/60 second. Thus, the desired inverse proportionality between the actual exposure time t' ($= t + T$) and the brightness of the fluorescent screen (magnitude of photoelectric current) would not be strictly realized. To correct for this small but not insignificant error, a resistor R was inserted in the phototube circuit as shown in fig. 6.

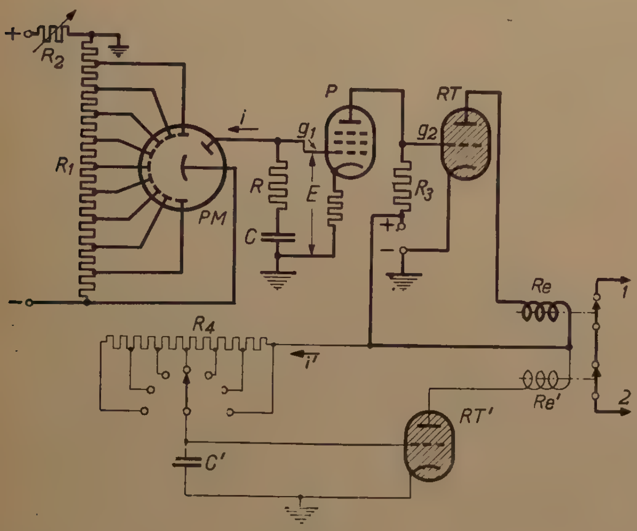


Fig. 6. Simplified circuit diagram of the photoelectric timer (heavy trace) and the safety timer (light trace). The current i of the photo-multiplier tube PM charges the capacitor C. This means that the potential of grid g_1 of pentode P will gradually grow more negative, the anode current of the pentode and hence the voltage drop on resistor R_3 will decrease, and the potential of grid g_2 of the relay-tube RT gradually will grow more positive. When the voltage on the capacitor C (plus resistor R whose role is explained in the text) reaches the value E, grid g_2 has become positive to such a degree that the relay-tube RT is fired, the relay Re is tripped and the power supply of the X-ray tube, conducted via *1-2*, is interrupted. (The relay-tube must be of a type firing at positive grid voltages.) The voltage between two successive electrodes of the photo-multiplier tube, tapped from potentiometer R_1, is controlled by the variable series resistance R_2. In this way the amplification factor, on which depends the density of the fluorogram attained, is adjustable between wide limits. — The relay Re' of the safety timer is tripped by the triggering of another relay-tube RT', whose grid potential (in contradistinction to the grid potential of RT), is rising at a rate independent of the screen illumination, owing to the capacitor C' being charged by a current i'' derived from the power supply. By adjusting this current by means of the variable series resistance R_4, the safety timer can be preset to a desired exposure time limit. — After an exposure, both relay tubes are quenched by interruption of their anode circuit; similarly, both capacitors are discharged, and recharging begins when the X-ray tube again is loaded.

Without the resistor, the following equation would hold:

$$\frac{i \cdot t}{C} = E, \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

where C is the capacitance of the capacitor, charged by the photoelectric current i, and E the voltage across it necessary for firing the relay-tube. Thus the total exposure time would be

$$t' = t + T = \frac{CE}{i} + T.$$

With the resistor, however, we have instead of (1):

$$\frac{i \cdot t}{C} + i \cdot R = E. \quad . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

Hence

$$t' = t + T = \frac{CE}{i} - RC + T.$$

Choosing R so that

$$RC = T,$$

we get

$$t' = \frac{CE}{i},$$

i.e. the desired constancy of the product $i \cdot t'$, which determines the density of the fluorogram, is achieved.

The automatic timer may also be used in making full size radiographs, if this is desired. In that case the timer is automatically set for proper full size radiograph density by throwing the corresponding switch on the control panel. The ease with which full size pictures may be taken in this way is very important for assignments in isolated places: as soon as the film has been processed and inspected, the suspicious cases thus discovered can be picked out for normal radiography with the same equipment.

In this section a few remarks are added concerning the reliability of the whole apparatus. Special care was devoted to this point, because on many assignments the apparatus is to be used at large distances from its home base so that possible troubles might cause considerable delay for want of proper servicing facilities. An important feature in this respect is that the X-ray tube, which is normally supplied with full-wave rectified a.c., can also be made to work on self-rectification (provided the type of tube adopted is suited for a.c. supply). In the normal case, the tank unit mentioned earlier, containing a complete bridge circuit of four high vacuum rectifying valves immersed in oil and a transformer for the filament current of the X-ray tube, is connected in series with the two high tension transformer units; cf. *fig. 7*. Obviously the rectifying valves and the X-ray tube are the most vulnerable parts of the equipment, possessing a limited (though very long) life. As a rule, a spare X-ray tube is carried with the equipment, but it would hardly be feasible to carry along a spare specimen of the rather heavy rectifier unit as well, and replacement of a single rectifying valve at the site is not convenient because of the oil-filling. Therefore, the cathode unit (A') of the high tension transformer is provided with an additional filament transformer which is not in operation under normal conditions, but which renders it possible to connect the X-ray tube directly to the transformer, bypassing the entire rectifier unit. Thus, in an emergency, a survey already in progress can be continued with a.c. voltage on the X-ray tube. However, the rating of the tube will be lower in this case and one must be satisfied with a lower quality of the radiographs.

Similar provisions, insuring continuation of a survey in progress, have been made for the photoelectric timer and for the motordrive unit used for the vertical adjustment. Each of these can be readily detached and replaced in its entirety by another unit; or, if desired, a non-automatic hand- or clockwork-timer can be substituted for the photoelectric timer, and the manual adjustment substituted for the motor drive.

X-ray protection

In connection with an X-ray survey involving great numbers of exposures executed at all kinds of sites, in factories, class rooms, barracks etc., it is evident that special attention must be paid to X-ray protection. It need hardly be mentioned that the X-ray tube must be of the ray- (and shock-) proof type, allowing a cone of X-rays to emerge only in the direction of the examinee. A further conventional measure is the protection of the operator against the radiation scattered from the examinee, the fluorescent screen, etc.: he is placed behind a protective screen (cf. fig. 2) provided with lead glass windows. The protective screen consists of sheet steel and has a thickness of 1/16″, equivalent to 0.25 mm of lead. Weight reduction by selection of suitable material was not possible in this case, as the effectiveness of the screen in absorbing X-rays depends directly on its weight.

If the exposures are made with the help of other personnel standing near the examinee, these persons likewise must be protected by means of similar screens.

The danger that might arise for other persons through excessive exposure to radiation, even if the X-ray tube is pointed — as it should be — toward an outer wall or an empty room, is minimized with this apparatus by placing a diaphragm before the X-ray tube window, cutting off all the rays of the primary cone which would not strike the fluorescent screen. As provision is made for three different focal spot-to-screen distances, the distance desirable for full size radiography being different from that for fluorography, a different properly related position of the diaphragm is provided in the diaphragm holder for each of these distances (cf. *fig. 8 a, b, c*), in order to insure the exact limitation of the primary radiation to the screen in all three cases.

The radiation cone itself is not sharply limited, owing to the finite width of the focal spot (1.5 mm with rotating anode tubes, 4 tot 5 mm with stationary anodes); a "half-shadow" or penumbra, gradually widening at increasing distances from the tube, is present around the useful cone. This half-shadow region necessarily must fall outside the screen, lest a decrease of density toward the edges of the image be obtained. As is

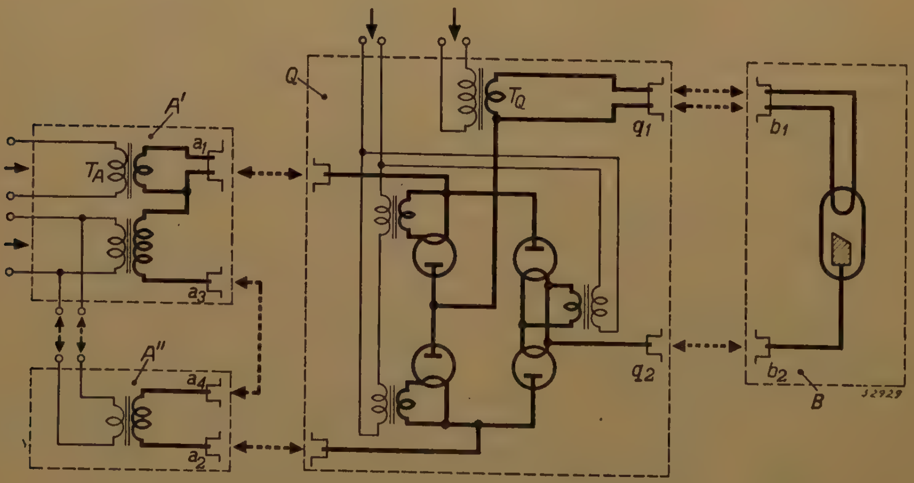


Fig. 7. Circuit diagram of the power supply of the X-ray tube (B). A' and A'': high tension transformer units, each delivering 50 kV, 200 mA. Q: rectifier unit, containing four rectifying valves and the filament transformer T_Q for the X-ray tube. The receptacles a_1 and q_1 are identical, and so are a_2 and q_2. Thus the entire rectifier unit Q can readily be eliminated in case of a breakdown of one of the valves, the cable from b_1 being plugged into a_1, that from b_2 into a_2: the spare filament transformer T_A automatically takes over the supply of the X-ray tube filament. The X-ray tube then is run with self-rectification.

seen from fig. 8*d*, the undesired half-shadow region will be reduced by placing the abovementioned diaphragm (D_1) at a greater distance from the tube. In order to be able to do so without unduly increasing the flange width of the diaphragm designed to absorb the useless outer parts of the primary cone, a second diaphragm (D_2) nearer to the X-ray tube is provided. This intercepts a large part (*IV*) of the useless outer rays, leaving the exact limitation of the remaining cone to be performed by the first diaphragm (D_1), whose size is in this way kept within reasonable limits.

Equipment for survey of hospital admissions

Among the groups of persons eligible for a systematic chest survey, hospital admissions have been named as one of the most important. Considering the fact that, in the United States, e.g. about 16 000 000 hospital admissions per year occur, it is seen that an appreciable part of an entire population could be surveyed in this way. With respect to organization, the examination of hospital admissions is a comparatively easy job, and with respect to possible consequences, the recognition of cases of tuberculosis with these persons (and with hospital personnel) is particularly important. Experience already obtained 7) demonstrates that about 1.5 to 4.3% of the admissions (depending on age, living standard etc. of the groups examined) show significant tuberculous disease. Incidentally, 10 to 20% exhibit non-tuberculous abnormalities of the lungs, heart, spine or other parts visible on the radiographs.

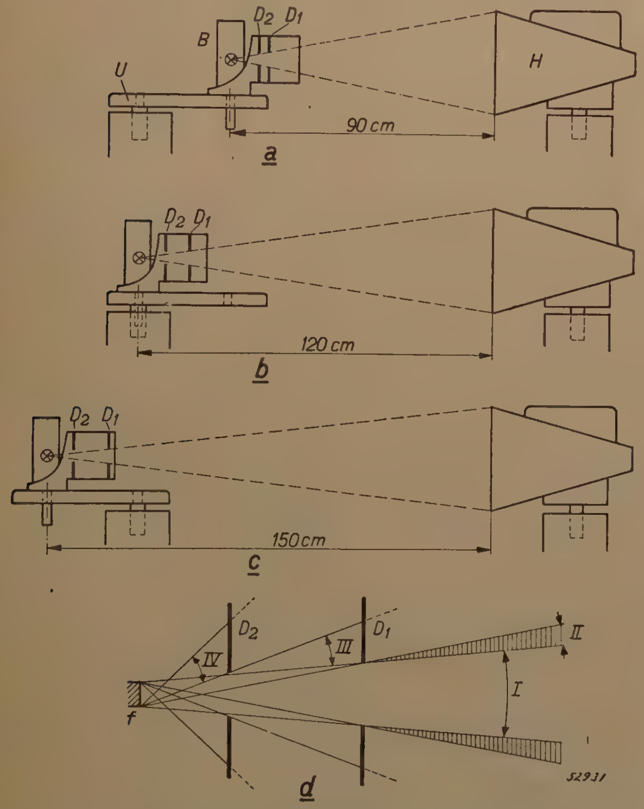
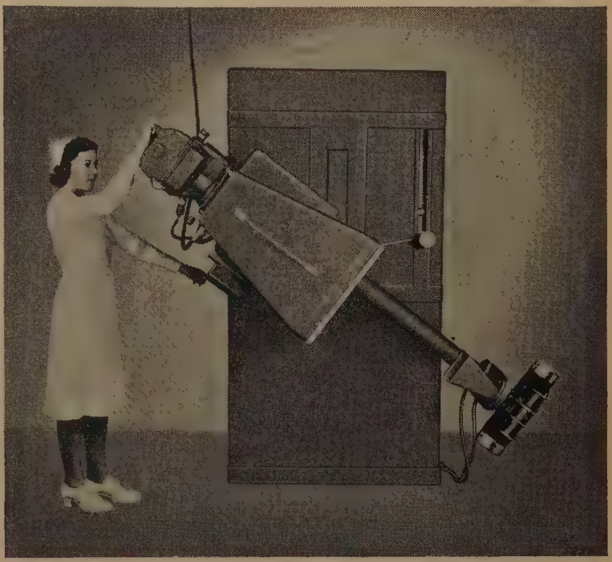


Fig. 8. Limitation of the cone of X-rays, emitted by the X-ray tube *B*, to the solid angle subtended by the hood *H* (screen surface) by means of diaphragm D_1. The tube can be fixed at three different distances from the hood, as the tube-supporting bracket *U* contains two holes for the alternative insertion of the tube dowel pin, and moreover, the bracket can be placed on its pedestal in a forward or backward direction (*a*, *b*, *c*). In accordance with these three different focal spot-to-screen distances, the diaphragm D_1 must be placed in the corresponding one of three different positions marked on the diaphragm holder. The auxiliary diaphragm D_2, which permits the size of diaphragm D_1 to be kept small, remains in a fixed position in all three cases. Owing to the finite width of the focal spot *f*, the cone of X-rays transmitted by the diagraphm is not sharply limited (*d*). Only part *I* of the cone may be used for the irradiation of the fluorescent screen; parts *III* and *IV* are absorbed by the flanges of diaphragms D_1 and D_2; part *II* is the half-shadow.



ig. 9. Mass chest survey equipment for hospital admissions. To enable fluorograms of incoming stretcher patients to be taken, the X-ray tube and hood can be swung to a vertical alignment.

X-ray equipment for this special survey work in hospital locations need not be transportable, but on the other hand, it must meet the requirement of being suited for both ambulant and non-ambulant patients. North American Philips Co., Inc., has designed a specially adapted equipment for this purpose, cf. *fig. 9*. The X-ray tube and the hood in this apparatus are mounted at opposite ends of a supporting arm which can be swung through an arc of approximately 100°, thus providing the possibility of horizontal radiography for patients lying on a stretcher. In other respects, this apparatus is essentially similar to the one described above.

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7) The following statements are taken from a report issued in 1946 by the Council on Professional Practice of the American Hospital Organization. In this report is mentioned a 1943 questionnaire sent to 934 major hospitals, which revealed that 46 of them had already adopted the chest survey of all admissions as a routine practice. To-day it has undoubtedly been adopted by many more.

THE FUNCTION OF THE COATING OF WELDING RODS

by J. D. FAST.

621.791.753:66.046.58

In a previous article the physico-chemical factors playing a part in welding with bare rods have been discussed. In the present article the requirements that have to be met by the coating of welding rods are analysed. Firstly the nature of the forces bringing about the transfer of the metal is gone into and the circumstances are investigated under which iron oxide in the coating may cause porosity of the welds. The protection afforded by the slag against oxygen and nitrogen is discussed, starting from an ideal case where liquid iron is covered with a simple slag consisting solely of liquid SiO_2. Attention is then directed to more complicated slags and finally the coatings and slags applied in welding technique are discussed. It appears that satisfactory protection against oxygen can only be obtained if the use of oxides with a heat of formation less than about 100 kcal per gram atom oxygen is entirely avoided in the coating. Maximum protection against nitrogen requires the use of slags with low solubility for this gas. In additon to the requirements for protection against oxygen and nitrogen, for the transfer of the metal and the avoidance of porosity, the coating and the slag have to fulfil other functions, which are likewise discussed here. These requirements are so numerous and so divergent that it was necessary to develop various types of welding rods each possessing a certain number of favourable properties. The most important types manufactured by Philips are discussed.

Introduction

In a previous article ¹) we have seen that in order to make welds having satisfactory mechanical properties it is necessary to provide the welding rods with a coating. It is from the material of this coating that the slag is formed which has as its main purpose the protection of the molten metal against the attack of oxygen and nitrogen.

Coatings of greatly differing composition are used, which is not surprising considering the various functions of the coating in addition to affording protection against oxygen and nitrogen. In this article we shall go more closely into these various aspects.

When thought is given to the function of the coating and we ask ourselves what material is most suitable we must firstly bear in mind that in practice one is obliged to use oxides, among other substances. If these oxides have relatively little stability (this is manifest, inter alia, in a not very great heat of formation) the iron that has to be protected may already absorb a quantity of oxygen as a result of the reaction with such oxides. This applies particularly to rods which have a coating containing large quantities of iron oxide and with which we shall become acquainted in this article under the name of type Ph 46 electrodes. With this type of rod there can be hardly any question of protection against oxygen, though its coating does afford a certain amount of protection against nitrogen. Rods which in addition to iron oxide contain in their coating reducing metal powders (type Ph 50 electrodes) offer much better protection, but still there is no question of complete protection against oxidation. To reach this, one must absolutely avoid the use of iron oxides and other oxides having relatively little heat of formation. Such is the case with the electrodes type Ph 55 and Ph 56.

Now in the article quoted in footnote ¹) it was shown that the forces driving out the droplets of iron during the welding process are due, in the case of bare electrodes, to the chemical reaction between the carbon present in the metal of the welding rod and the oxygen absorbed from the atmosphere. Effective protection against oxidation, as offered by the coating of the electrodes type Ph 55 and Ph 56, eliminates this reaction almost entirely. Here the function of the development of CO is taken over by substances in the coating which generate large quantities of gas during the welding process. The coatings referred to contain alkaline-earth carbonates, substances which were already used before one was aware of this important aspect of their function.

The use of iron oxide has yet other drawbacks than those already mentioned. We shall see that owing to its presence welds made with the type Ph 46 electrodes always contain pores. Under normal circumstances such is not the case when the type Ph 50 electrode is used, but slight changes in the conditions may likewise lead to porous welds.

Remarkably enough, the coatings containing iron oxide appear to offer less protection also against

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¹) J. D. Fast, The part played by oxygen and nitrogen in arc-welding, Philips Techn. Rev. 10, 26-34, 1948 (No. 1).

nitrogen than the coatings of the type Ph 55 and Ph 56 rods. At the end of this article (the closing paragraph in small type) we shall see that this is related to the fact that the slags formed out of the coatings containing iron oxide have greater solubility for nitrogen. In this connection it must be borne in mind that although it prevents direct contact between the metal and the atmosphere the slag is apt to absorb oxygen and nitrogen from the atmosphere and transmit this to the metal through diffusion and turbulences. In order to explain both this question and the reaction between coating (respectively slag) and metal we shall consider in this article an ideal case where liquid iron is covered with a very simple slag consisting of liquid SiO_2. After dealing with that case we shall discuss the more complex slags used in welding technique and investigate in how far the electrode coatings answer the requirements that have to be made. It will be found that these requirements are related not only to the protective action and the formation of gases but also, inter alia, to the melting range, the electron emission, the viscosity and the expansion coefficient of the material comprising the slag. The article closes with a more detailed discussion of the various types of welding electrodes. There a type will be referred to which has not hitherto been mentioned, the type Ph 48 electrode, which has relatively large quantities of organic materials in the coating.

The part played by gases coming from the coating in the transfer of the metal and in the penetration

When welding with the type Ph 46 and Ph 50 electrodes (which contain iron oxide in their coating) the carbon content of the metal is reduced by at least some hundredths per cent by oxidation, so that, just as is the case with bare rods, the reaction between oxygen and the carbon in the rod may contribute towards the transfer of the metal. That this is not the only determining factor when using coated electrodes, however, is evident from the fact that with the electrodes type Ph 55 and Ph 56 (coating: waterglass + CaF_2 + $CaCO_3$ + reducing metal powders) overhead welding can quite well be done, although with this type of electrode the slag affords such a good protection that there is virtually no reduction of the carbon content.

In order to ascertain the origin of the force which in this case drives out the droplets at such a high speed, we heated some of these rods for two hours in a stream of argon at 850 °C, thereby driving the chemically bound H_2O and CO_2 out of the coating. It was then found that after this heating it was no longer possible to make an overhead weld with these electrodes. At the tip of the electrode drops were formed which became larger and larger until ultimately they fell off. There was virtually no transfer to the workpiece at all. This is illustrated in *fig. 1.*

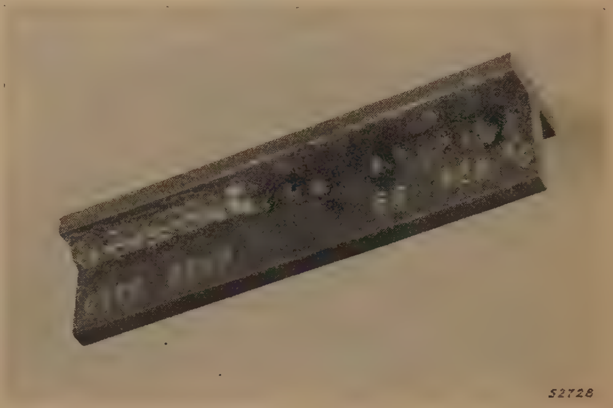

Fig. 1. The effect of heating a coated electrode (type Ph 56) for two hours in a stream of argon at a temperature of 850 °C. The left half of the workpiece shows an overhead weld made with a normal type Ph 56 rod. After a rod had been heated in the manner described it was found impossible to make an overhead weld, although an expert welder did his very best. As the right half of the workpiece shows, only a few drops of the welding material could be deposited on the workpiece, so that there was no question of any weld being made.

On the other hand the rods of this type when not previously heated to 850 °C are exceptionally suited for overhead welding. This is due to the fact that the smaller the oxygen content the greater is the surface tension and the viscosity of the molten metal. The oxygen content of the metal deposited from the type Ph 46 and Ph 50 electrodes is so high that when making overhead welds the liquid iron has a tendency to drip down out of the pool.

From the foregoing it appears that the gases driven out of the coating when welding with electrodes not previously heated to 850 °C tend to take over the previously described function of the formation of CO at the tip of the electrode. Under the influence of these released gases the drops are thrown off at a high velocity. Furthermore, a strong stream of hot gas blows against the workpiece and makes for good penetration (*fig. 2* illustrates what is meant by this). This jet action when welding with coated electrodes not heated to 850 °C is apparent also from the fact that after the welding is completed there is always a so-called crater [2]) in the solidified metal.

A good coating should therefore be capable of producing a powerful stream of gas during the welding process. This requirement is usually met by adding carbonates or organic substances to the coating. The gases are evolved partly in the form of H_2O and CO_2 and partly (i.a. owing to reaction with the reducing metal powders in the coating) as H_2 and CO. As shown experimentally by Mallett[3]), the water-gas equilibrium is established between these gases in the vicinity of the arc

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[2]) In welding technique the crater is understood to be the oval depression in the solidified metal at the end of a bead.

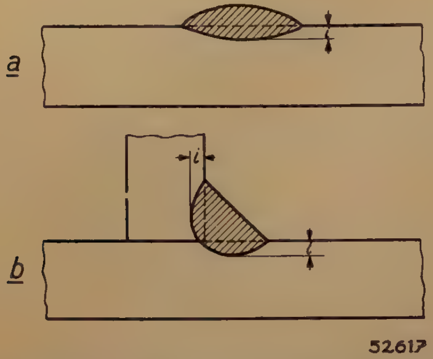

Fig. 2. The depth to which the metal of the workpiece is melted is called the penetration. This is indicated by the letter *i*: *a*) for a bead on a flat plate, *b*) for a horizontal fillet.

$$H_2O + CO \rightleftarrows H_2 + CO_2 \; . \; . \; . \; . \quad (1)$$

The arc gases from the type Ph 55 and Ph 56 electrodes have a very low content of H_2O and H_2. This is because these electrodes before leaving the factory are heated to such a temperature that the carbonates in the coating are not dissociated but the bound water is for the greater part expelled. Consequently when welding with this type of rod the molten metal can hardly absorb any hydrogen at all, with the great advantage that one need have no fear of encountering the difficulties likely to arise from the release of this gas. Without going into them more closely we may say that the main difficulties are the occurrence of porosity and, when welding steels having a relatively high carbon content, the occurrence of cracks in the transition zone ("underbead cracking").

The part played by iron oxide in the occurrence of porosity in beads

Apart from the so-called hydrogen porosity referred to above, under certain circumstances (particularly when using electrodes which have iron oxide in the coating) there may also be trouble from CO porosity. With the type Ph 50 electrodes, the coating of which contains, among others, iron oxide and reducing metal powders (ferromanganese and ferrosilicon), the proportions are so chosen that in normal working sound, non-porous welds are obtained.

If the reducing metal powders are removed from the coating, then owing to the increased development of CO in the molten metal the welds become highly porous. It is a remarkable fact that also reduced formation of CO seems to lead to porosity of the welds, as may appear from the following experiments.

Thick-walled tubes of mild steel (ext dia. 25 mm, int. dia. 4 mm) were closed at one end by welding and then filled with a rod of aluminium, titanium or zirconium of a high degree of purity and of such a length as to leave about 8 mm of the steel tube vacant. Then the open end of the tube was sealed by welding, but before doing so, this end was plugged with a conical steel pin in order to avoid oxidation of the Al, Ti ot Zr. The rods with a core made in this manner were then hammered and drawn out to wire of 4 mm gauge, cut to length (after removing the ends) and provided with coatings of the Ph 50 type. The beads obtained with these welding rods were highly porous, whereas 4 mm rods of ordinary mild steel with the same coating gave perfectly sound beads.

There is little room for doubt that the evolution of gas that always takes place in the molten pool is greatly reduced by the addition of Al, Ti or Zr to the core wire. In certain cases therefore reduced gas formation seems to have a tendency to increase porosity. This is probably to be attributed to the fact that when they are evolved very slowly the gases are more easily enclosed in the solidifying metal. This is in agreement with what has been experienced in the manufacture of steel [4]).

Further evidence of this is found in the fact that Doan and Smith, when carrying out welding experiments in helium and argon (see the article quoted in footnote [1])) obtained beads which were much more porous than when welding in the air. Here again there can be little doubt that when welding in helium or argon less gas is evolved in the molten pool than when welding in the air.

The equilibrium between liquid SiO_2 and liquid Fe.

Having considered the nature of the forces driving out the droplets at such a high speed when welding with coated electrodes, and having ascertained under what conditions the presence of iron oxide in the coating may lead to porosity of the welds, we shall now consider more closely the protection afforded by the slag against oxygen and nitrogen.

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[3]) M. W. Mallett, Welding J. 25, 396s-399s, 1946.

[4]) See for instance A. Hultgren and G. Phragmen, Trans. A.I.M.E. (Iron and steel division) 135, 133-244, 1939.

All slags employed in the technique of welding contain SiO_2 and we shall therefore first direct our attention to the equilibrium existing between SiO_2 and liquid Fe:

$$2Fe + SiO_2 \rightleftarrows 2FeO + Si \; . \; . \; . \; . \quad (2)$$

The position of this equilibrium can be calculated by thermodynamic methods from heats of reaction, specific heats, heats of fusion and heats of solution [5]). In this reaction not inconsiderable quantities of FeO are formed, the greater part of which dissolves in the SiO_2 and the smaller part in the iron.

Table I gives the calculated Si and O equilibrium contents of the metal and the FeO content of the slag for different molar ratios of SiO_2/Fe and at a temperature of 2000 °K.

Table I. Calculated compositions of metal and slag for the equilibrium between liquid SiO_2 and liquid Fe at 2000 °K.

Molar ratio SiO_2/Fe	Metal		Slag
	wt % Si	wt % O	wt % FeO
1/16	0.12	0.083	3.45
1/8	0.15	0.074	3.09
1/4	0.20	0.064	2.67
1/2	0.28	0.054	2.23

The values given in table I are not claimed to be absolutely accurate, but anyhow they show that even in the absence of oxygen in the gaseous state not inconsiderable quantities of oxygen may be absorbed by the liquid iron by reaction with a chemically pure SiO_2 slag. At the still higher temperatures reached by the iron when arc-welding, the equilibrium relations are in this respect even still more favourable.

It is fortunate, however, that welding takes only so short a time that one always keeps fairly far away from the state of equilibrium. Moreover, table I shows that the iron also absorbs a quantity of Si much greater than is necessary for a complete binding of the dissolved oxygen to SiO_2 during the cooling process.

If air is present as a third phase we must also take into account (as already remarked) the fact that the slag does not offer complete protection against this, because it will always possess a certain degree of permeability for gases.

Permeability of the SiO_2 slag for oxygen and nitrogen

From measurements taken by various investigators it may be deduced that a wall of pure SiO_2 (quartz glass) 1 mm thick and with a surface area of 1 cm^2 under a pressure difference of 1 atm on either side of the wall allows quantities of oxygen to pass through which, for a temperature T between 950 and 1200 °K, are given by the equation

$$m = 1.2 \cdot 10^{-2} \, e^{-15600/T} \text{ gram } O_2/\text{hr.} \; . \; . \quad (3)$$

Under the same conditions and within the same temperature range the permeability for nitrogen is expressed as

$$m = 1.75 \cdot 10^{-3} \, e^{-12600/T} \text{ gram } N_2/\text{hr.} \; . \quad (4)$$

This permeability is due to the fact that oxygen and nitrogen have a certain though small solubility in quartz glass. As a result there is apt to be a diffusion current from one side to the other. At first sight one might think that this must have serious consequences for arc-welding. However, even for a temperature of 2500 °K the order of magnitude of the permeability found with the aid of the formulae (3) and (4) is only 10^{-5} gr/hr. Of course we dare not by any means maintain that such a large extrapolation is permissible, but even if the permeability at 2500 °K were for instance a factor 100 greater than that found here it would be insignificant under the conditions of arc-welding.

In the composite slags actually used for arc-welding, which we shall consider more closely farther on, there may, however, be a much greater solubility and a much greater permeability. Moreover, at high temperatures the viscosity of the slags used in welding is so low that convection currents in the slag may also considerably accelerate the transmission of gas.

As soon as the slag contains a quantity of FeO in solution (and according to table I this is already the case in the state of equilibrium if we start with pure Fe and pure SiO_2 in the absence of a gas phase) the permeation of oxygen may also be brought about by an entirely different mechanism. On the outer surface of the slag oxygen can be continuously chemically bound, bivalent iron being converted into trivalent iron. This reaction can be expressed by the formula

$$4\,Fe^{++} + O_2 \rightarrow 4\,Fe^{+++} + 2\,O^{--} \; . \; . \quad (5)$$

Inversely, at the boundary between slag and metal trivalent iron can again be reduced to bivalent iron:

$$2\,Fe^{+++} + Fe \rightarrow 3\,Fe^{++}, \; . \; . \; . \quad (6)$$

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[5]) For these calculations reference is to be made to an article that will shortly be published in Philips Research Reports.

iron being transferred from the metal to the slag. In the liquid slag there will then be a continuous transport (owing to convection and diffusion), ferro-ions (Fe^{++}) moving outwards and ferri-ions (Fe^{+++}) and oxygen ions moving inwards. Electrons too may contribute towards this transport, since at the high temperatures prevailing SiO_2 already possesses a certain degree of conductivity for electrons. Consequently the inward flow of the ferri-ions may be wholly or partly replaced by a movement of electrons in the opposite direction.

The various processes discussed lead to a continuous increase in the iron oxide content of the slag and if there were time enough ultimately all the iron would be taken up in the slag in the form of oxide.

Regarded from the point of view of the states of equilibrium, the slag therefore offers no protection at all, as could be predicted. The final stage is always the complete oxidation of the iron. In fact, however, slags do indeed afford protection against oxidation because in welding the reaction time is only very short, so that we keep at a safe distance from the state of equilibrium. Moreover, usually there are added to the slag-forming coatings of the welding rods reducing metal powders such as ferro-silicon (45% Si and 55% Fe), ferro-manganese (80% Mn and 20% Fe) and ferrotitanium (25% Ti and 75% Fe), which bind the oxygen penetrating into the slag and, if added in sufficient quantity, even deposit a metal with higher Si and Mn contents than those of the core wire. This brings us, however, into the domain of the slags as used in welding technique, which we shall consider further in the following.

Composite slags

When discussing in the two preceding sections the protection offered by a coating we confined our considerations to slags consisting entirely of SiO_2 or, after reaction with the liquid iron, of SiO_2 + a little FeO. We chose this course because it allowed a more or less quantitative treatment and because SiO_2 is an essential component of all slags used in practice.

Actually, however, welding is impossible with rods having a coating consisting almost entirely of SiO_2. Owing to its high melting point such a coating would not melt uniformly with the metal but would form a tube that becomes longer and longer until at last the distance between the core wire and the workpiece would become too great and the arc would be extinguished. It is therefore necessary to use coating containing other oxides in addition to SiO_2.

We shall mention here some experiments carried out with mixtures consisting of only three of these oxides, viz. SiO_2, CaO and Al_2O_3[6]). These experiments show that a state of equilibrium will no more be established between the components of the slag during welding than between the metal and the gaseous atmosphere (see the foregoing and the article quoted in footnote [1])).

In the aforementioned system two ternary compounds occur, anorthite $CaAl_2Si_2O_8$ ($CaO \cdot Al_2O_3 \cdot 2SiO_2$) with a melting point of 1550 °C and gehlenite $Ca_2Al_2SiO_7$ ($2CaO \cdot Al_2O_3 \cdot SiO_2$) with a melting point of 1590 °C. These compounds form a quasi-binary system with a eutectic point of 1385 °C. See the diagram in *fig. 3*.

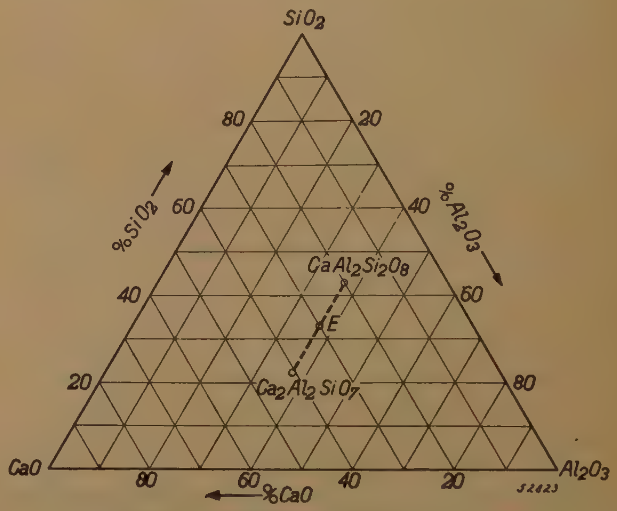

Fig. 3. In the ternary equilibrium diagram SiO_2 - CaO - Al_2O_3 two congruently melting ternary compounds occur, anorthite ($CaAl_2Si_2O_8$) and gehlenite ($Ca_2Al_2SiO_7$). These form a quasi-binary system with eutectic *E* of 1385 °C (see the dotted line).

For these experiments rods of mild steel (diameter 4 mm) were coated with mixtures containing 30% CaO, 37% Al_2O_3 and 33% SiO_2 (all % by wt), the composition of the aforementioned eutectic. This was done in three ways:

a) by coating with a mixture of $CaCO_3$, Al_2O_3 and SiO_2,

b) by coating with a mixture of anorthite and gehlenite, both obtained by mixing $CaCO_3$, Al_2O_3 and SiO_2 in the proportions corresponding to these compounds and sintering separately for a long time at 1340 °C [7]).

c) by coating with a eutectic obtained by melting $CaCO_3$, Al_2O_3 and SiO_2 in the right proportions in an oven.

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[6]) Experiments by J. L. Meyering and W. P. van den Blink not published.

[7]) It is to be assumed that during the sintering the oxides are not fully converted into the compounds.

When welding with the rods coated in this manner that with the coating a) gave a slag with a much too low viscosity. The viscosity rose considerably, however, in the order a)-b)-c), so much so that as far as the viscosity is concerned the slag formed from the coating c) almost came up to the requirements made in practice. Still, even in the case c) the slag could not be said to be technically useful, because, inter alia, it did not sufficiently wet the metal. It showed a tendency to agglomerate into separate drops (see the next section). This was one of the causes of the great porosity of the beads obtained in these experiments.

The great difference in viscosity between these three slags of the same gross composition leads to the conclusion, already mentioned, that in the short welding time no state of equilibrium can be reached in the slags.

In agreement herewith, when measuring the viscosities of molten mixtures of CaO, SiO_2 and Al_2O_3 McCaffery [8]) found that after melting the viscosity needed a certain time (in some cases as much as one hour) to reach a constant value. One might imagine that in the welding experiments described when the coating a) is used a metastable eutectic liquid with a low viscosity is formed and that a much longer time would have been needed to cause the viscosity to rise through the formation of anorthite and gehlenite molecules.

In the following sections we shall consider the mixtures applied in actual practice. First of all we have to see what requirements these mixtures have to meet. At the same time it will be necessary to make a sharper distinction between coating and slag, because, as is evident from the foregoing, chemical reactions may take place during melting not only in the coating itself but also between the coating (or the slag) and the metal. As a consequence there may be great differences in chemical composition between the coating and the slag.

Requirements to be met by coatings and slags

As we have seen, the slags discussed in the preceding sections do not come up to the requirements met in practice. Moreover, only a few of these requirements have so far been mentioned.

Besides the conditions referred to in the foregoing, the coating and the slag have to satisfy the conditions that will be summed up below. Those discussed under a)-d) relate particularly to the coating and the others mainly to the slag.

a) *Cup formation*

As seen from the foregoing (in the beginning of the previous section), one of the first requirements to be met by the coating is that it must have such a low melting range as not to form too long a cup when welding. This is illustrated in *fig. 4*, a diagrammatic representation of the process of welding with coated rods. On the other hand, the melting range may not be so low as to prevent the formation of a cup, for the cup has the useful function of directing the arc and the stream of droplets passing from the electrode to the workpiece. A satisfactory cup is obtained when the melting range lies in the neighbourhood of 1200 to 1300 °C.

b) *Welding without interruptions*

Apart from their use with direct current, in many cases welding rods have to be used with alternating current, which is practically impossible with bare electrodes. The automatic reignition of the arc following every currentless moment when alternating current is used is closely connected with the electronic emission from certain components of the coating.

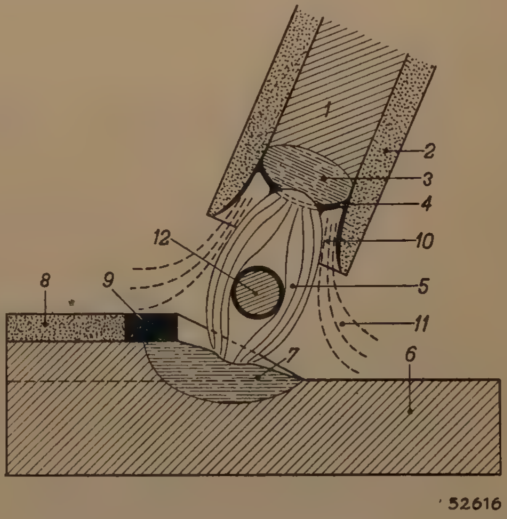

Fig. 4. Diagrammatic representation of the process of welding with a coated electrode (see J. Sack, Philips Techn. Rev. 2, 129-135, 1937). *1* core of the electrode, *2* coating, *3* liquid metal, *4* liquid slag, *5* electric arc, *6* workpiece, *7* pool, *8* solidified slag, *9* liquid slag, *10* cup, *11* protective gases, *12* droplet covered with slag.

c) *Cohesion between the metal and the metal of the workpiece*

In order to be sure of making a strong joint certain requirements are made as to the depth to which the metal of the workpiece is melted during the welding process, i.e. the penetration already mentioned. As we have seen, the depth of the penetration is directly related to the evolution of gases from certain components of the coating during the welding.

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[8]) R. S. McCaffery, Trans. A.I.M.E. (Iron and steel division), 100, 64-140, 1932.

d) *Mechanical properties of the weld.*

In some cases the requirement is made that the coating must have an alloying action, so that the deposited metal becomes richer in certain alloying elements (usually Mn and Si) than the original core wire. This requirement is made in order to obtain welds having special mechanical properties. Obviously this alloying action can only be fully brought about when the coating is of such a composition as to satisfy the primary requirement in respect to the protective action against oxygen and nitrogen, or, in other words, when it would already lead to very good mechanical properties even without an alloying action.

e) *Viscosity of the slag*

The viscosity of the slag formed from the coating may not be too high, as is, for instance, the case with slags having a very high SiO_2 content. It may not, however, be too low either, because then (particularly in the case of vertical and horizontal fillets) the slag would run off the weld too readily, with the risk of the still hot metal being exposed to the attack by oxygen and nitrogen.

f) *Spreading of the slag*

The slag must not agglomerate. The condition that a drop of slag spreads itself out over liquid iron is expressed by

$$\sigma_{\mathrm{Fe}} > \sigma_{\mathrm{slag}} + \sigma_{\mathrm{Fe\text{-}slag}} \quad . \; . \; . \; . \; . \quad (7)$$

where σ_{Fe} and σ_{slag} represent the surface tensions of iron and slag and $\sigma_{\mathrm{Fe\text{-}slag}}$ denotes the iron-slag interfacial surface tension. If the condition (7) is satisfied then there is a reduction of the free energy in the spreading. The surface tension of the slag and the metal-slag interfacial surface tension must therefore be relatively low. This spreading also inproves the appearance of the weld.

g) *Breaking away of the slag*

The slag must have an expansion coefficient differing as much as possible from that of the metal, so that when it cools down it easily breaks away, preferably of itself. This is also promoted by porosity of the slag.

h) *Various other requirements*

Among various other requirements, it should be possible to use the rods in all positions and, further, the welding speed should be high.

The requirement a)-h) are so numerous and so divergent that it is impossible to satisfy them all at the same time, even with a coating consisting of a large number of components, so that the development of a coating for welding electrodes is always of the nature of a compromise. Different types of electrodes will be used according to whichever group of requirements weighs most. Below we shall discuss four of the most important types, which for the sake of simplicity we shall denote as *A*, *B*, *C* and *D*. First of all it is to be noted that with practically all types the coating materials are used in the form of fine powders, which are applied to the rods with the aid of potassium waterglass or sodium waterglass having a high SiO_2 content.

The different types of welding electrodes

Type A (e.g. Ph 46). For the simplest types of electrodes with inorganic coatings the powders consist for a large part of quartz and natural silicates (talc $Mg_3\,[Si_4O_{10}(OH)_2]$; kaolin $Al_4\,[Si_4O_{10}\,(OH)_8]$; asbestos $Mg_6\,[Si_4O_{11}\,(OH)_6]\cdot H_2O$, etc.). In order to reduce the melding range and viscosity, iron oxides (hematite Fe_2O_3; magnetite Fe_3O_4) and manganese oxides (pyrolusite MnO_2; hausmannite Mn_3O_4) and sometimes also titanium dioxide (rutile TiO_2) are added. Further, in order to promote electron emission and also to produce a stream of gas (see requirement c) alkaline-earth carbonates are added (calcareous spar $CaCO_3$, magnesite $MgCO_3$ and dolomite $CaMg(CO_3)_2$).

Owing to the high iron oxide content of the slags obtained with these rods, the oxidation of the weld metal is almost as serious as when using bare electrodes. The oxygen contents found in the welds are comparable to those for bare rods, given in table I of the article quoted under footnote [1]) whilst the C, Mn and Si contents are reduced to almost equally low values. The welds made with these rods have, therefore, poor mechanical properties compared with those obtained when using the types of electrodes *B*, *C* and *D*, though, owing to the much lower nitrogen content of the deposited metal, the mechanical properties are much better than those obtained with bare electrodes.

Rods of the type *A* are especially used in cases where mechanical strength is of minor importance and the main consideration is easy weldability and good appearance of the beads (for instance, for welding sheet metal and for very light constructions). The welds are internally porous owing to the reaction between oxygen and carbon in the molten metal.

Type B (e.g. Ph 50), In order to obtain electrodes which deposit a metal with better mechanical properties, appreciable quantities of ferromanganese and ferrosilicon are added to the coatings.

From the chemical point of view this solution of the problem is a remarkable compromise, because the coating then contains both oxidizing and deoxidizing substances. The exothermic chemical reaction between these substances, however, contributes towards a high welding speed. The mechanical properties of the deposited metal are more than sufficient for most applications. The oxygen content, however, is still rather high (about 0.12 wt % O), so that it is still possible to improve further the mechanical properties.

Type C (e.g. Ph 55). If rods are required with exceptionally good mechanical properties one should entirely avoid the use of iron oxides in the coating. The slag should only contain oxides of which the heat of formation ΔH per gram atom of oxygen (or rather the free enthalpy of formation ΔG) is very large. The oxides of *table II* for instance, can be used. By way of comparison we may state that the values of ΔH and ΔG for Fe_2O_3 and Fe_3O_4 lie between —67 and —60 kcal per gram atom of oxygen [9]).

Table II [9]). High-melting oxides with large heat of formation ΔH and a corresponding free enthalpy of formation ΔG.

Oxide	ΔH	ΔG
	kcal per gram atom of O	
Al_2O_3	—131	—124
BeO	—145	—
BaO	—133	—126
CaO	—152	—144
MgO	—146	—138
SiO_2 (quartz)	—104	— 97
TiO_2	—112	—106
ZrO_2	—129	—

With this type of rod fluorite (CaF_2) is added to the coating as a fluxing agent. The most commonly used rod of this type has a coating consisting mainly of $CaF_2 + CaCO_3$ in addition to waterglass, with additions of ferromanganese, ferrosilicon and ferrotitanium. The quantities used are as a rule such that the Mn and Si contents of the weld are higher than those in the core wire, thus giving greater mechanical strength and ductility (cf. requirement d). The O content of the deposited metal is only 0.03%.

A drawback attaching to these rods is the frequent extinction of the arc when working with alternating current, unless a welding machine is used with a dangerously high no-load voltage. This extinguishing of the arc is found to be particularly promoted by the calcium fluorite contained in the coating and can be eliminated by ensuring that this substance has less chance of getting into the immediate vicinity of the focus of the arc. This has been achieved by applying the coating in two or more layers around the rods, in such a way that the calcium fluoride is contained mainly in the outer layer. Such a "shell rod" is marketed by Philips under the type number Ph 56. This electrode can be used on alternating current at a no-load voltage of about 60 V without trouble being experienced from extinction of the arc.

Type D (e.g. Ph 48). The coating of this type of rod contains large quantities of organic substances which evolve a great deal of gas during the welding process and thus keep the oxygen and nitrogen away from the metal. At the same time the coatings contain slag-forming inorganic substances in respect to which the same remarks apply as have been made under the types *A*, *B* and *C*. The O content of the metal deposited from electrodes of the type *D* lies between that of the types B and C.

The core wire used in all these four types of electrodes is usually of mild steel. The differences between the various types and the metals deposited from them lie almost exclusively in the different coating. For special purposes there are also on the market electrodes having a core wire of entirely different composition, but these are left out of consideration here.

A disadvantage when welding with the types of rods described is that the welder must maintain a definite arc length (about 3 mm). If the arc becomes too long the weld has an irregular appearance and insufficient penetration, whilst further there is much loss from spattering. If the arc length is too short the electrode "freezes" to the workpiece. Particularly with havy gauge rods it is difficult to maintain the correct arc length.

In the latest types of welding rods this objection has been overcome by incorporating a large part of the iron in the coating in the form of a powder. This gives a coating of such thickness and strength as to allow of touch-welding with these rods. For a more detailed account of these so-called "contact" electrodes we refer to two articles that have been published in this journal [10]).

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[9]) Following international usage that is gaining more and more ground, a quantity of heat (or work) added to a system is said to be positive. Consequently an exothermic chemical reaction has a negative heat of reaction.

[10]) P. C. van der Willigen, Philips Techn. Rev. 8, 161-167 and 304-309, 1946. In these articles various other advantages are summed up which are connected with welding with contact electrodes. The "contact" electrodes corresponding to the types Ph 48, Ph 50 and Ph 55 are marked C 18, C 20 and C 15 (C = contact).

The absorption of nitrogen in arc-welding

Remarkably enough, the nitrogen content of the deposited metal varies with the type of rod in the same sense as the oxygen content. As a typical example, the metal obtained from the Ph 55 and Ph 56 (type *C*) has 0.03% O and 0.01% N, whilst the metal from the Ph 50 (type *B*) has 0.12% O and 0.03% N. This seems to indicate that the slag of the latter type absorbs nitrogen out of the air and passes it on to the metal more readily than the slag of the former type.

The apperance of the slags points in the same direction. Whereas the Ph 55 gives a dense crystalline slag, the Ph 50 produces a slag which is highly porous and vitreous. This leads one to suppose that at high temperatures the latter slag dissolves gases readily, part of the gas being subsequently released in the cooling process, thereby causing porosity. The fact that under certain circumstances oxidic masses of comparable composition can dissolve large quantities of gas is known from the volcanic phenomena [11]).

If nitrogen were one of the gases readily soluble in the Ph 50 slag we might find herein an explanation for the relatively high nitrogen content of the welds made with rods of this type. In order to check this, quantities of slag obtained from welding the Ph 50 and Ph 55 rods were pulverized (in order to avoid the complication of gases contained in the pores) and high-frequency heated in platinum crucibles in vacuo. The gases evolved in the melting of the slags were drawn off and analysed. From the slag of the Ph 50 about 2 cm^3 of gas (of 0 °C and 1 atm) per gram slag was released, accompanied by strong frothing. The slag of the Ph 55 did not froth and generated only a fraction of the amount of gas released from the other slag. *Table III* gives the composition of these gases in so far as they were not condensable at —80°C (the content of water vapour was not determined).

Table III. Composition (in volume per cent) of the gases released when melting slags from the electrodes Ph 50 and Ph 55.

Gas	Ph 50 vol. %	Ph 55 vol. %
CO_2	2	46
CO	23	51
CH_4	5	—
H_2	60	1
N_2	10	2

These figures may be taken as a confirmation of the supposition previously expressed that the higher nitrogen content of the metal deposited from the Ph 50 is related to the greater solubility of this gas in the slag.

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[11]) See for instance P. Niggli, Das Magma und seine Produkte, Teil 1, Akademische Verlagsgesellschaft, Leipzig 1937.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk can be obtained free of charge upon application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Netherlands.

1760: C. J. Bouwkamp: On the construction of simple perfect squares (Proc. Kon. Ned. Akad. Wetenschappen, Amsterdam, **50**, 1296-1299, 1947, No. 10)

Correction to a previous paper (these abstracts **1719-1721**). Construction of a simple, perfect, squared square of 55 elements.

1761: Balth. van der Pol: An electro-mechanical investigation of the Riemann Zeta function in the critical strip (Bull. Am. Math. Soc. **53**, 976-981, No. 10).

A known representation of Riemann's ζ-function ($\zeta(s)$), valid for Re $s > 1$, is analytically continued in the strip $0 < \text{Re}\, s < 1$. For $s = {}^1/_2 + it$ this representation may be written as the Fourier-integral of a certain saw-tooth function. The zero's and maxima of this integral are obtained by an electro-optical method, the Fourier-integral being approximated by a Fourier series. A disc carrying the saw-tooth function on its circumference rotates before a photoelectric cell. The amplitudes of the harmonics of the resulting periodical time function are plotted as a function of their number.

1762: A. Cramwinckel: The sensitivity of various phototubes as a function of the color temperature of the light source. (J. Soc. Mot. Pict. Eng. **49**, 523-529, 1947, No. 61).

A method is described for measuring the sensitivity of various types of phototubes (Cs_2O vacuum and gas-filled, Cs-Sb vacuum, Se) as a function of the temperature of the light source (tungsten ribbon lamp). The results are compared to the function giving the brightness of a complete radiator as a function of temperature. For light sources with high color temperature (3000 °K) the Cs-Sb cell is at least two times as sensitive as the Cs_2O vacuum cell.

1765: J. D. Fast: De rol van zuurstof bij het electrisch lassen (The influence of oxygen in electric arc welding, Meded. Vlaamse Chem. Ver. **10**, 1-21, 1948 Jan., in Dutch).

For the contents of this paper see Philips techn. Rev. **10**, 27-35, 1948 (No. 1), Philips Res. Rep. **2**, 205-227, 1947 (No. 3) and these abstracts No. **R 47**

1766: F. L. H. M. Stumpers: Distorsie van signalen met frequentiemodulatie bij doorgang door electrische netwerken. (Distorsion of frequency modulated signals, in electrical networks, T. Ned. Radiogen. **13**, 1-21, 1948 no. 1, in Dutch).

The distortion, introduced when a frequency-modulated signals passes through electrical networks, is calculated using Fourier analysis or the series of Carson and Fry. The methods used by these authors are studied and their series is shown to be not convergent but asymptotic. An alternative asymptotic series development is given, which is more adapted to F.M. The theory is applied to simple networks: single tuned circuit, coupled circuits. The production of harmonics as well as intermodulation is considered.

1767: A. Claassen and J. Corbey: On the electrometric determination of vanadium in steels (Rec. trav. chim. Pays Bas **67**, 5-10, 1948, No. 1).

Procedures are given for the electrometric determination of vanadium in alloy steels. In tungsten-free steels vanadium is determined by titration with ferrous sulphate under specified conditions of acidity. It is shown that this method gives low results for steels containing tungsten, due to the imcomplete reduction of the vanado-phosphato-tungstate complex; complete reduction however takes place by boiling with excess ferrous sulphate, enabling the determination to be finished by electrometric titration with standard permanganate. Small amounts of vanadium accompanied by large amounts of tungsten can only be determined by titration with ferrous sulphate when the amount of phosphoric acid is greatly increased.

1768 *: P. J. Bouma: Physical aspects of colour, an introduction to the scientific study of colour stimuli and and colour sensations, 312 pages, 113 figs, 15 tables and extensive list of references (Edited by Philips Gloeilampenfabrieken, Philips Technical Scientific Library Department, 1948).

For the contents of this book, being the English version of "Kleuren en Kleurindrukken" by the same author (in Dutch), see the review given in Philips techn. Rev. 9, 159, 1947. A few sections and minor contributions have been added, e.g. on colour equations, the systems of Ostwald and Munsell, heredity, etc.

1769*: E. J. W. Verwey and J. Th. G. Overbeek (with the collaboration of K. van Nes): Theory of the stability of lyophobic colloids, the interaction of sol particles having an electric double layer, 205 p., 54 fig. (Elsevier Publishing Company Inc. New York, Amsterdam, London, Brussels, 1948).

The purpose of this book is to explain the stability of hydrophobic colloids and suspensions and to develop as far a possible a quantative theory of this stability.

The basic concepts of this theory were the mutual repulsion consequent upon the interaction of two electrochemical double layers, and the attraction by the London-Van der Waals forces. The principal facts of stability could be explained by combining these two forces. Among other things, a quantative explanation of the rule of Schulze and Hardy has been given. For this purpose it was essential to use the unapproximated Gouy-Chapman equations for the double layer. The approximation of Debije and Hückel, however useful in the theory of electrolytes, appears to have only a very limited applicability in colloid chemistry.

The introduction of several refinements was necessary to explain various details. The quantitative agreement between theory and experiment made it necessary to reckon explicitly with the dimensions and the specific adsorbability of the ions. To this end, Stern's theory has been introduced.

Repeptization phenomena cannot be understood without the introduction of the Born repulsion, which, however, apart from this, is of very minor influence on the stability properties.

The results proved that the London theory also needed a certain rectification in the form of a relativistic correction, because the uncorrected theory led to conflicts with the experiments in the case of coarse suspensions. The book consists of three parts, dealing with the theory of a simple double layer, the interaction of two flat plates, and the interaction of spherical colloidal particles respectively. In an appendix a survey of theoretical work on the stability of lyophobic colloids by previous authors is given. See also Philips Res. Rep. 1. 33-49, 1945/46.

1770: M. J. O. Strutt and A. van der Ziel: Application of velocity-modulation tubes for reception at U.H.F. and S.H.F. (Proc. Inst. Radio Engns **36**, 19-23, 1948 no. 1).

Upon introduction of the notions of gain and noise figure, it appears that preamplifier stages using velocity-modulation tubes are unsuitable at u.h.f. and s.h.f. under operational conditions considered hitherto. A special arrangement, connected with such a tube and consisting of three electrode pairs spaced along the electron stream, is considered in this paper. The first pair is connected to a resonance cavity or line, constituting a pre-circuit. The second pair is connected to the input, an the third pair to the output circuit. It can be shown that the transfer of initial spontaneous velocity fluctations to density fluctations along the electron stream may be neglected. The reserve effect is considered in an appendix, and it also is negligible under practical conditions. It is shown that, by the use of a properly detuned pre-circuit, the noise figure may be reduced from a few thousand to, say, 10 under optimal conditions retaining gain figures of, say, 100. The usefulness of the arrangement under consideration is discussed and estimated to be favorable under actual conditions of operation. With traveling-wave tubes noise figures below 10 are thought to be attainable by application of the present device.